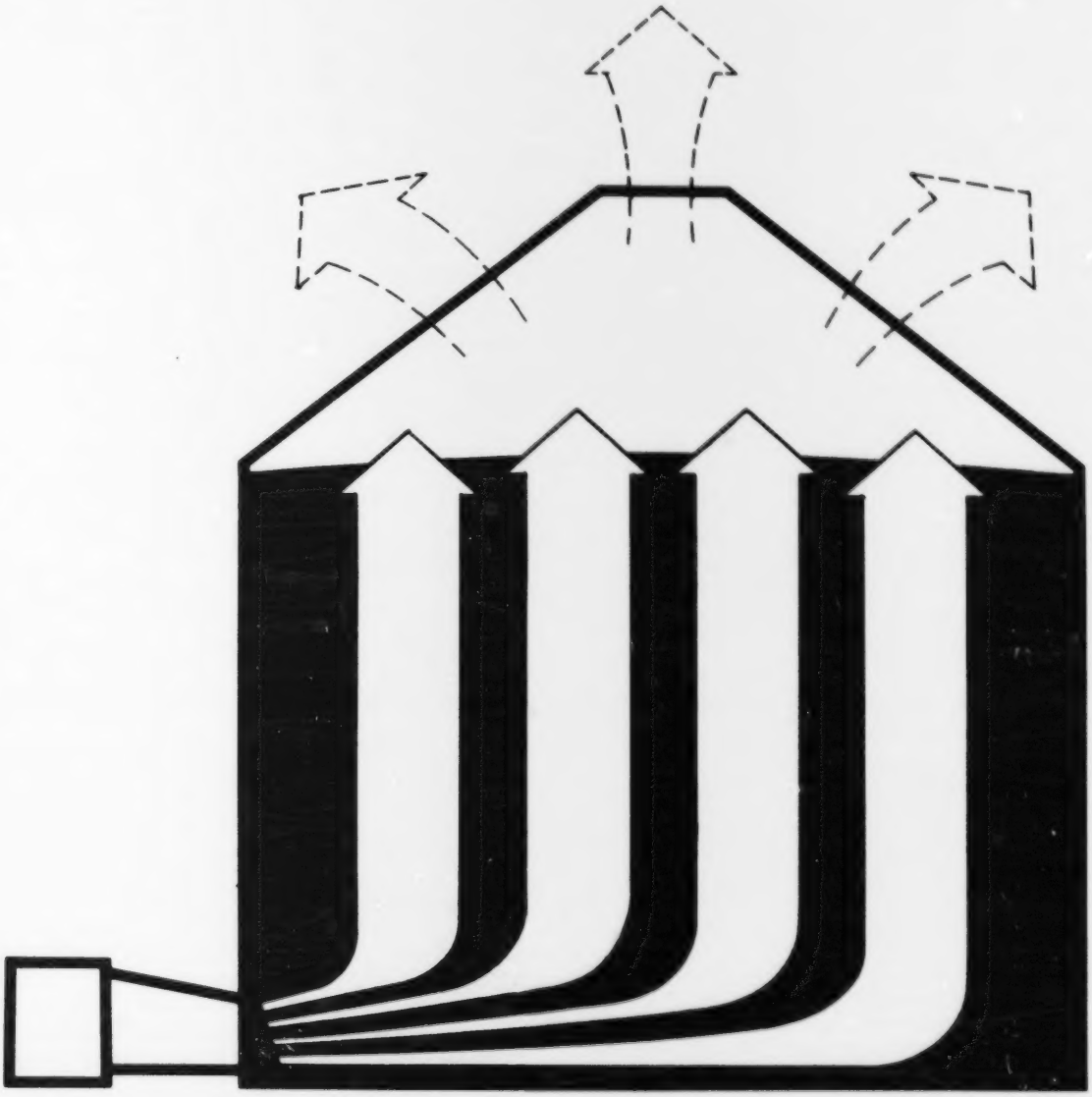
Manitoba Agriculture

GRAIN AERATION and UNHEATED AIR DRYING



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GRAIN AERATION AND UNHEATED AIR DRYING

Keeping grain cool and dry is the most effective method of ensuring safe grain storage. High grain moisture content and high temperatures encourage mold growth and insect activity, which lead to spoilage. Figures 1 to 3 show the allowable storage times for several crops at various temperatures and moisture contents before spoilage begins.

A number of processes are used to dry or cool grain, each involving passing unheated air through grain. These include: aeration, unheated air drying, dryeration and in-storage cooling.

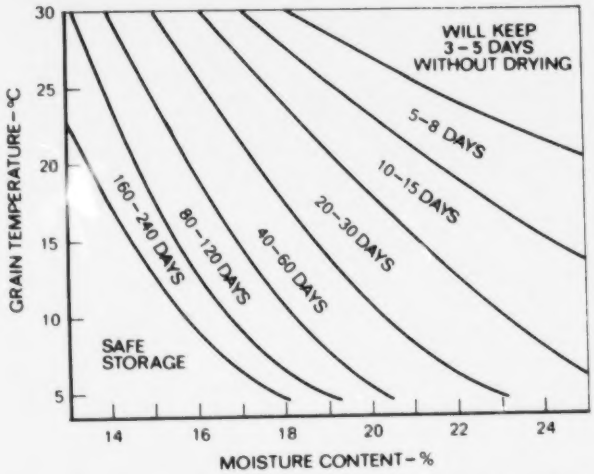


Figure 1. Effect of Temperature and Moisture Content on Allowable Storage Time of Wheat, Oats and Barley.

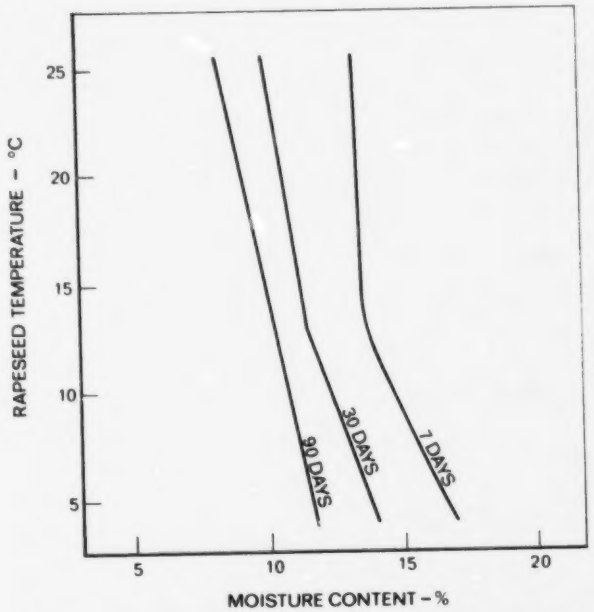


Figure 2. Effect of Temperature and Moisture Content on Allowable Storage Time of Continuously Ventilated Rapeseed.

1. AERATION

Aeration is the use of relatively low airflow rates to cool grain and eliminate temperature and moisture differences in the storage bin. Aeration may be used with field dried grain

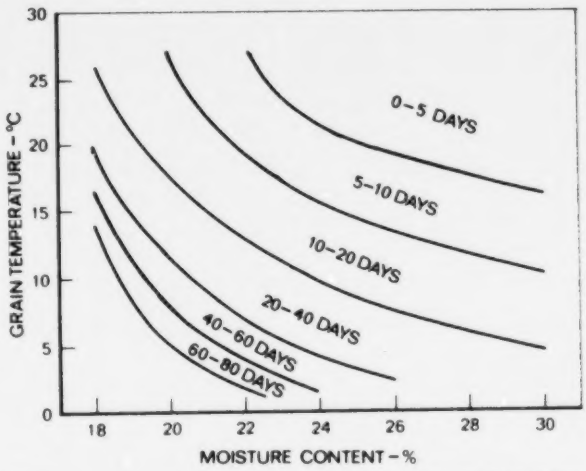


Figure 3. Effect of Temperature and Moisture Content on Allowable Storage Time of Corn.

or with grain that is harvested damp, then dried and cooled in a heated air dryer. In both cases, temperature and moisture content variations may exist in the grain, or the grain may be too warm to store safely. Variations in grain temperature are also caused by changes in the outside air temperature after the grain is stored.

Temperature differences can cause moisture to move (migrate) from warmer to colder areas of the bin. Figure 4 shows

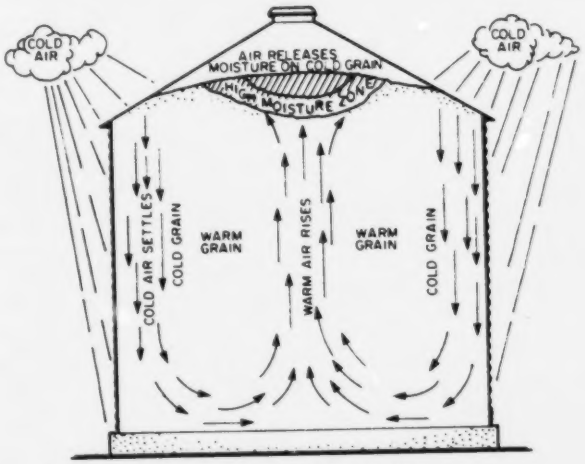


Figure 4. Moisture Migration in Fall & Winter.

moisture migration patterns when temperature differences are created by lower ambient surrounding temperatures. Warm air rising in the centre of the bin cools when it reaches the cold grain near the surface. This results in an increase in moisture content near the surface which can lead to rapid spoilage. Crusting on the surface of stored grain is a common symptom of moisture migration. In summer, it is possible to get moisture migration in the opposite direction if the outside temperature is warmer than the grain, as shown in Figure 5. Significant migration can occur in cereal grains at moisture contents as low as 12 per cent or oilseeds as low as 8 per cent if they are placed into storage at a high temperature and not cooled.

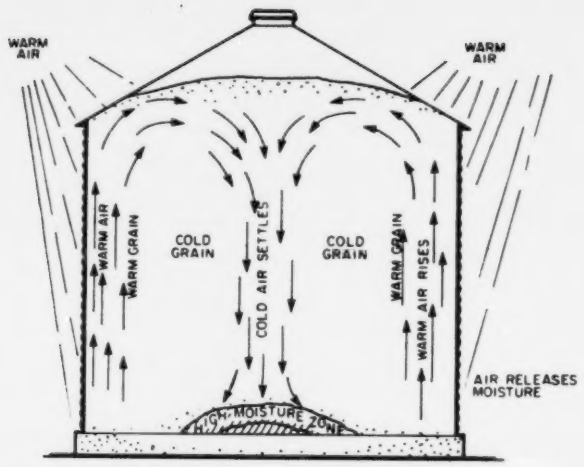
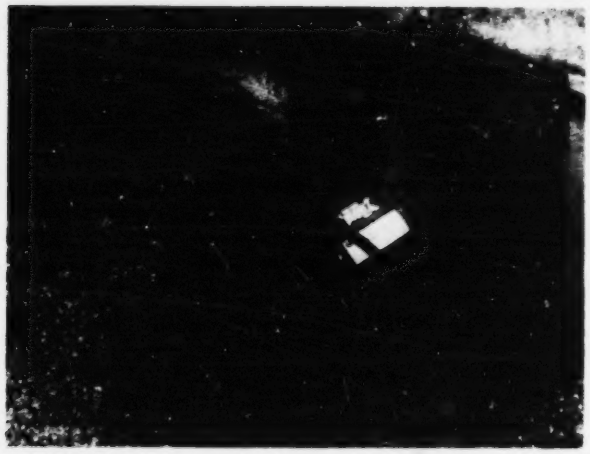


Figure 5. Moisture Migration in Spring & Summer.

Larger storage bins and greater differences between grain and ambient temperature cause more moisture migration. In western Canada, wide ambient air temperature variations necessitate the use of aeration systems, particularly for large storage bins (100 m³ or larger). Large bins provide more opportunity for the development of the convection currents which cause moisture migration.

The purpose of an aeration system is to produce the lowest practical temperature and the least temperature variation within the stored grain. Proper management of aeration systems is needed to achieve these goals. Details are given in the section entitled "Management of Aeration Systems".

The amount of air required to change the temperature of the grain will produce very little change in moisture content. Aeration is not a grain drying system and should not be considered as such. Under ideal weather conditions some drying occurs during aeration but the low airflows used are not sufficient for reliable safe storage of grain that is more than 1 per cent above "dry", unless grain temperatures are near or below 0°C. The airflow rates for aeration are normally one to two litres of air per second per cubic metre of grain [1-2 (L/s)/m³]. Unheated air drying rates are normally much higher than this.



Aeration Fan

With an airflow rate of 1 (L/s)/m³ about 150-200 hours of fan operation are needed to change the temperature throughout the bin. With an airflow rate of 2 (L/s)/m³ it takes only one half as long. It is essential for the fan to be operated long enough to equalize the temperature throughout the entire bin. The temperature of the grain must be checked to see when cooling is completed. Recommended monitoring points are shown in Figure 6.

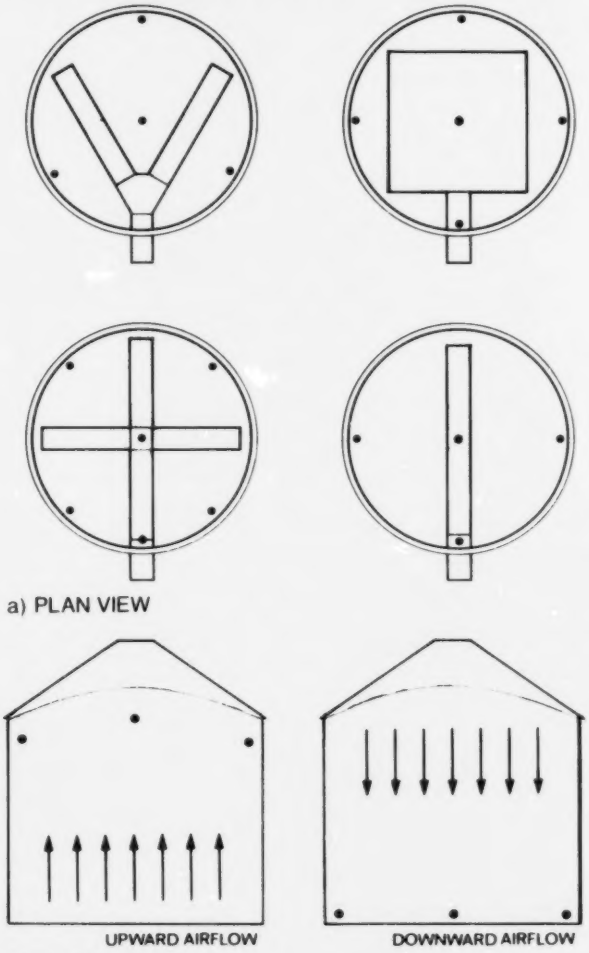
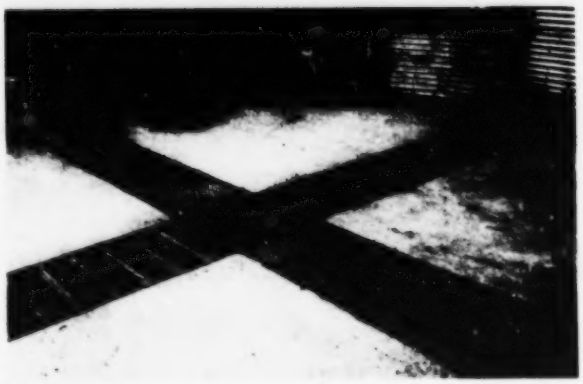


Figure 6. Sampling Locations for Bins with Partially Perforated Floors.

Management of Aeration Systems

Fall During the fall, grain must be cooled as quickly as possible. Cooling will occur whenever the exhaust air temperature from the grain is at least 5°C above the maximum daily outside temperature. Run the fan day and night as long as this condition exists, regardless of relative humidity. A day or two of fan operation during rainy weather or other high relative humidity periods does no harm if the fan operates for a day or two of fair weather afterwards. Grain does not gain moisture as quickly as it loses moisture, so it is unlikely to gain enough in a few days to cause any problems. If the grain is dry, avoid extensive fan operation during rain or wet weather after the grain has cooled to within 5°C of the average outside air temperature.



Cross Duct

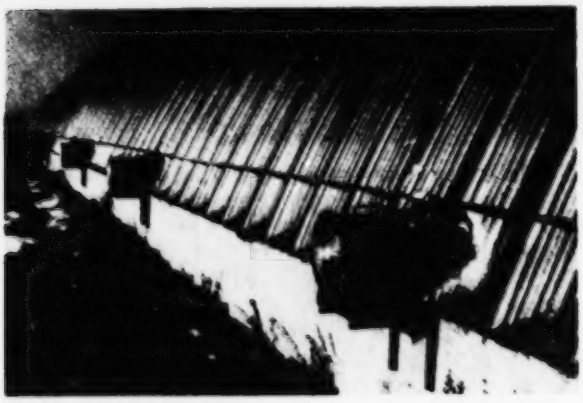
Turn the fan on to start aerating as soon as the grain is delivered to the bin. Grain cooled in a heated air dryer or grain harvested on warm, sunny days will always be warmer than the surrounding air and should be cooled as soon as possible. Check cooling progress and run the fan long enough to cool the grain to within 5°C of the average outside temperature. If the grain is placed into the bin at temperatures above 15°C, it should be cooled in several steps. For example, if the grain goes into the bin at 30°C it should be cooled to 20°C or lower as soon as possible. When the outdoor temperature drops sufficiently it should then be cooled to 10°C, and finally to 0°C for winter storage.

Check the temperatures at the points indicated on Figure 6 to determine when cooling is completed.

Winter When the fans are off during the winter holding period, cover the intakes with metal, canvas, or plywood to prevent the grain near the ducts from being cooled excessively in severe winter weather, and to prevent rodents from entering the ducts.

Check the grain temperature once a week during the winter holding period. Run the fan if there is any evidence of an increase in grain temperature. If there are any insects present, they can be killed by keeping the temperature at the following levels for the designated times:

Grain temperature	Time
-5°C	6 weeks
-10°C	4 weeks
-15°C	2 weeks



Aeration in a Flat Storage

Spring If the grain is being moved out of storage by July and has not been cooled below 0°C, it does not need to be warmed in the spring. If the grain is being held beyond July, or if it is below 0°C, warming to 10°C is recommended in order to prevent large temperature differentials in the bin from producing moisture migration. This is done in several stages beginning in April. Run the fans in fair weather (night and day) when the average 24-hour temperature is about 5°C warmer than the grain and the average daily relative humidity is below 70 per cent. Operate the fan continuously until the bin exhaust temperature is about the same as the minimum daily ambient temperature. Be sure to warm the entire grain mass before stopping the fan. If the fan is shut off before all the grain has been warmed, some condensation may occur between the cooler and warmer parts of the grain mass. This may cause spoilage if the grain is left for more than a few days. Condensation is more extensive with larger temperature differences.

Summer Be sure that all the grain is warmed to 10°C by mid-June. Cover the fan intake when the fan is turned off during the holding period. If the grain is near 10°C and the fan intake is open, condensation can occur during warm, humid periods in summer. This may cause grain spoilage next to the ducts.

Check the grain periodically and run the fan when the average outside temperature is near 10°C and the relative humidity is below 70 per cent to maintain a uniform, cool temperature throughout the bin.

Direction of Air Movement

Aeration can be accomplished by moving the air upward or downward through the grain. The air delivery system will move about the same amount of air either way. There are advantages and disadvantages to each direction, but in most situations upward air movement is preferred.

Upward air movement permits aeration progress to be easily determined by checking the grain temperature at the top of the bin. Also, with an upward airflow, the fan can be started immediately upon filling and air leaving the duct will help to keep the perforations clear of fines as filling starts.

The only advantage of moving air down and exhausting it at the bottom is to minimize condensation on the underside of the roof when aerating warm grain in cold weather. If air is moved upward, the moisture in the warm air may condense on the cold bin roof. If the warm grain is aerated before the weather gets too cold this problem can be avoided. The grain should be cooled in several steps as the outside temperature drops as described in the section entitled "Management of Aeration Systems".

The uncertainty of knowing when aeration is complete is the main disadvantage of moving the air down through the bin, since the grain at the bottom is the last to cool and the hardest to check. A thermometer in the exhaust air, preferably on the suction side of the fan helps check aeration progress. However, it only reads the average exhaust temperature and may not indicate pockets of grain which are at a higher temperature. The operator must check for the completion of aeration by probing to the bottom of the bin with a thermometer or by checking the temperature of some grain unloaded from the centre bottom of the bin. Another disadvantage of downward air movement is that when warm grain

is added to the bin, the heat from the added grain is drawn through the previously cooled grain and warms it up again. When aerating grain in summer, it is particularly important to move the air upward and out of the bin rather than drawing the hot air from under the roof down through the rest of the grain.

Duct Systems for Aeration

Many duct and perforated floor arrangements are available for use with aeration systems. For cylindrical grain bins some of the most common include a single perforated duct across the bin floor, a cross duct, a V-shaped duct, and a rectangular perforated area in the centre of the bin (see Figure 7). These and others are satisfactory if there is a sufficient perforated area. A minimum of 15 per cent of the bin floor area should have perforated flooring for aeration systems in bins up to six metres high. A 10 m deep bin should have at least 25 per cent of the floor area perforated to avoid excessive air velocities. More details on minimum perforated floor and duct areas are given in Tables 7 and 8.

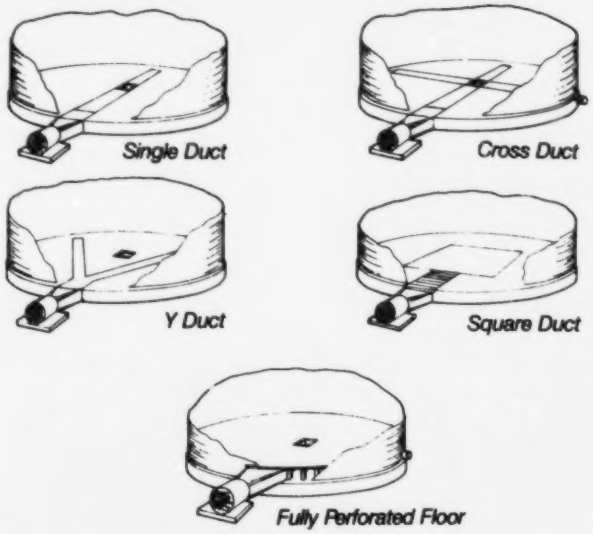


Figure 7. Aeration Ducts for Grain Bins.

Flat grain storages are difficult to aerate properly. Uniform air distribution is more difficult to achieve than in a cylindrical bin since the flat storage usually has a less uniform grain depth. Increased airflow helps compensate for some of the problems created by poorer air distribution. Airflow rates of 2 to 3 (L/s)/m³ should be used to help offset the distribution problems. Proper duct arrangement is important for a successful aeration system. Figure 8 shows some common duct arrangements that are used for flat storages. Arrangement (A) is preferred because it allows the grain to be cooled as soon as each duct is covered. In arrangement (B) the storage must be completely filled before aeration can begin. If the storage is only partially filled the duct must be blocked off one to three metres from the edge of the grain pile.

A lengthwise arrangement is adequate for aeration if the ducts are correctly sized and spaced. A good guideline to follow on duct spacing is to keep the longest air path from the duct to the grain surface no more than 1.5 times as long as the shortest air path. The number and spacing of the ducts according to this guideline is shown in Figure 9. For level-

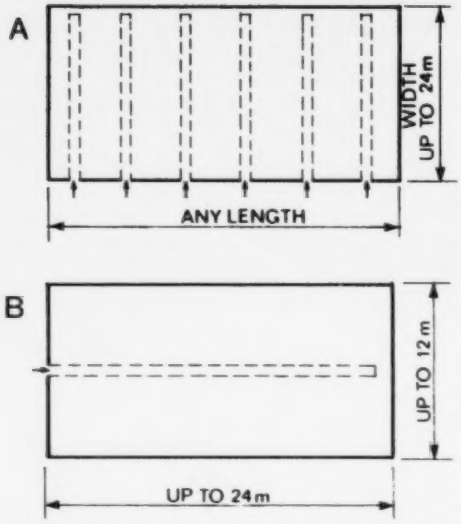


Figure 8. Aeration Duct Arrangements for Flat Storages.

filled flat storages, the duct spacing should be equal to the grain depth. Even when these guidelines are followed, the time required to finish cooling the grain will be considerably greater than if a fully perforated floor and level grain surface were used.

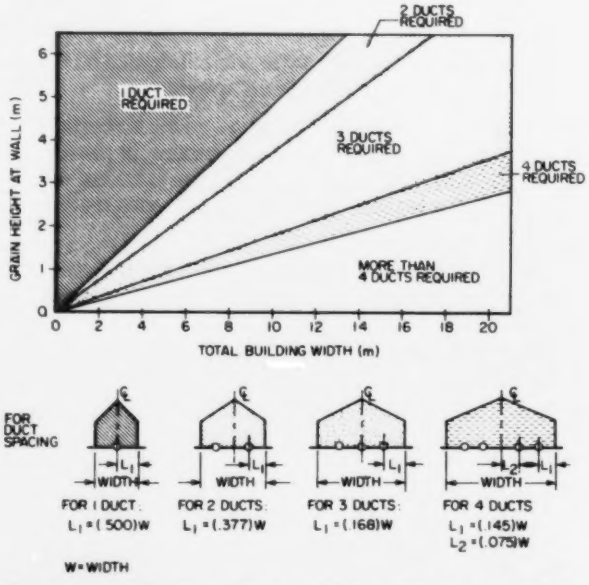

2 DUCTS REQUIRED
1 DUCT REQUIRED
3 DUCTS REQUIRED
4 DUCTS REQUIRED
MORE THAN 4 DUCTS REQUIRED
GRAIN HEIGHT AT WALL (m)
TOTAL BUILDING WIDTH (m)
FOR DUCT SPACING
WIDTH
FOR 1 DUCT: L1 = (.500)W
FOR 2 DUCTS: L1 = (.377)W
FOR 3 DUCTS: L1 = (.168)W
FOR 4 DUCTS L1 = (.145)W L2 = (.075)W
W = WIDTH

Figure 9. Lengthwise Ducts Required for Rectangular Buildings.

2. UNHEATED AIR DRYING

Unheated air drying uses the drying potential of surrounding air to remove moisture from grain. Air is normally forced into the bin from the bottom through a fully perforated floor and exhausted through roof vents. Some of the moisture in the grain evaporates and is removed by the air. The moisture transfer from the grain to the air takes place in the drying zone (see Figure 10). The grain above the drying zone remains at or near its initial moisture content. Grain located below the drying zone has a moisture content which is in equilibrium with the incoming air conditions. The equilibrium

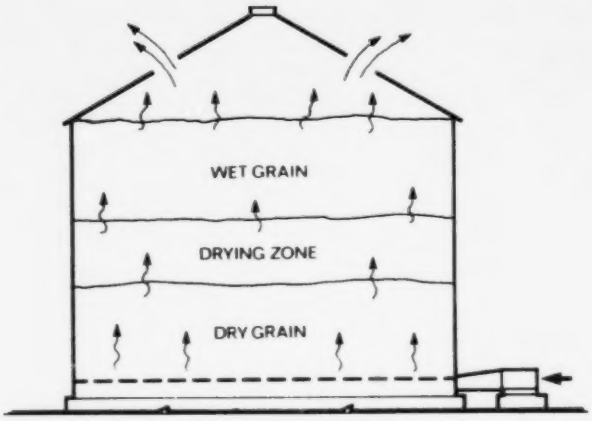


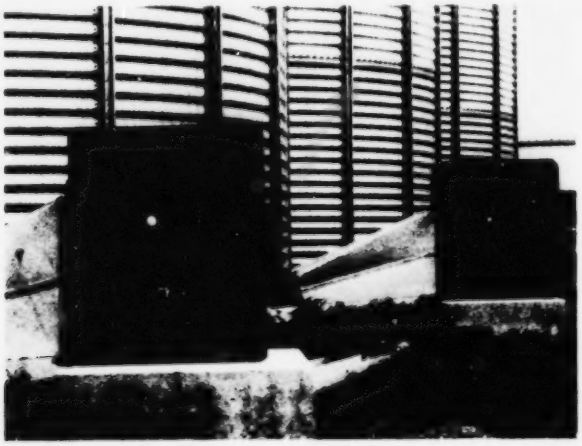
Figure 10. Unheated Air Drying.

moisture contents for wheat and canola (rapeseed) are given in Table 1. The equilibrium moisture contents for barley are about one per cent higher than for wheat.

TABLE 1

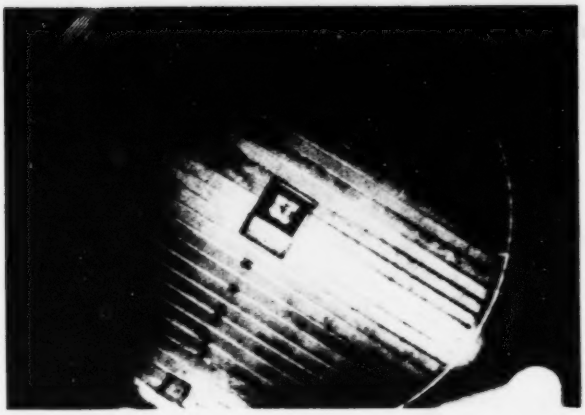
Equilibrium Moisture Contents

Relative Humidity of Air	Wheat Equilibrium Moisture Content at 25°C	Wheat Equilibrium Moisture Content at 10°C	Canola (Rapeseed) Equilibrium Moisture Content at 25°C	Canola (Rapeseed) Equilibrium Moisture Content at 10°C
58%	12%	13%	7.5%	8.6%
64	13	14	8.2	9.4
70	14	15	9.0	10.3
75	15	16	9.8	11.1
79	16	17	10.8	12.0
83	17	18	12.0	13.2
86	18	19	13.4	14.5



Unheated Air Drying Fans

Unheated air drying is a race to get the grain dried before it spoils. The key to success is to move the drying zone through the top of the grain mass within the allowable storage time. At higher moisture contents and temperatures, the allowable time for drying is reduced (see Figures 1-3). Wetter grain therefore requires higher airflow rates to accomplish drying within the allowable storage time. At higher temperatures, the grain deteriorates faster so higher airflow rates are required to complete drying before the grain spoils. The required airflow rates for various moisture contents and harvest dates are given in Tables 3A and 3B.



Fully Perforated Floor

Grain which is located at the top of the bin is likely to spoil first since it is the last to dry. The more air that is delivered, the quicker the drying zone moves through the grain and the shorter the time that the top layer is at risk. The fan should be operated continuously until the drying zone moves through the top of the grain or the temperature drops low enough for safe storage (see Table 2). The bottom layer of grain overdries in dry weather and re-wets in damp weather. However, as re-wetting occurs at the bottom, the drying zone continues to move upward. The rate of rewetting is slower than the drying rate so a few days of fan operation in wet weather will not seriously affect the overall drying rate. Also, the grain is kept cool by the air moving through it, which increases the allowable safe storage time.

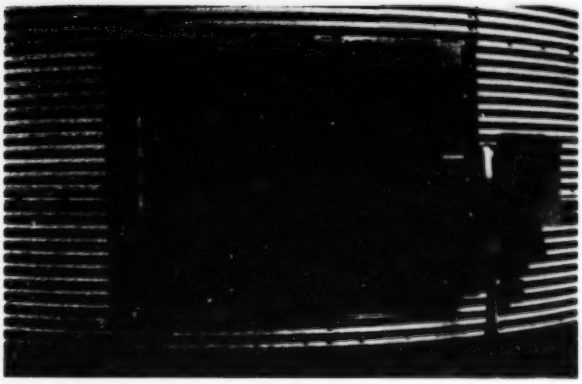
TABLE 2

Shut the fan off when

moisture content is below		AND grain temperature is below
Cereal Grains	**Oilseeds**	
20%	14%	0°C
18%	12%	5°C
16%	10%	10°C

Check the grain temperature twice a week.

Roof Vent and Ladders



Door Sealed to Prevent Air Loss

After the drying zone has passed through the grain, the grain should be cooled to near 0ºC for winter storage and the fan shut off. If drying isn't complete by early November, additional drying in spring may be required. Grain being fed to livestock during the winter can be used at moisture contents of 16 to 20 per cent. However, if the grain is to be marketed in the winter and the moisture content must be in the "dry" category, heated air drying may be required to complete the job.

If additional drying is necessary in spring, start the fan again in late March or early April and move another drying zone through the grain. If the grain has been partially dried in the fall, there will be less total moisture to remove in the spring and the drying zone will pass through the grain more quickly. As drying progresses in the spring, temperatures usually become warmer and humidities lower, causing grain located below the drying zone to continue drying. A series of drying zones may pass through the grain as drying conditions improve.

Grain at the bottom may be dried down below the desired moisture content by the dry, warm air conditions that often prevail in spring. This is a problem with any in-storage drying system and frequently occurs in August and September as well. Whenever the weather is very warm and dry, overdrying will occur at the bottom by the time drying is completed to the desired moisture level at the top.

Required Airflow Rates for Unheated Air Drying

The required airflow rate for unheated air drying depends on when the grain is harvested, its moisture content, the type of grain and the outdoor air conditions. Table 3A gives the recommended minimum airflow rates needed in Manitoba to dry wheat, barley and canola without loss of quality. These are based on computerized drying simulations using 33 years of Manitoba weather data. Future years could require higher airflow rates.

TABLE 3A

Recommended Minimum Airflow Requirements [(L/s)/m³] for Manitoba using a fully perforated floor and a level grain surface

Seed Wheat

Harvest Date	Dry Date		Moisture Content % 16	17	18	19	20	22
August 15	fall	100%	9	9	10	15	27	**
		97%	6	7	10*	15	27	**
		94%	5	6	10*	15*	27*	**
		90%	5	5	10*	15*	27*	**
	spring		6	7	10	15	27	**
% of time dried in fall			97%	97%	100%	100%	100%	**
Sept. 1	fall	100%	10	11	12	13	17	40
		97%	8	10	10	13*	17	40
		94%	7	9	10	13*	17	40*
		90%	7	8	9	13*	17	40*
	spring		7	8	8	13	17	40
% of time dried in fall			94%	91%	88%	100%	100%	100%
Sept. 15	fall	100%	19	23	28	30	32	37
		97%	17	22	23	24	25	27
		94%	13	13	16	17	20	27
		90%	10	12	15	16	17	26
	spring		8	8	8	8	14	26
% of time dried in fall			76%	73%	52%	33%	82%	88%
Oct. 1	spring		8	8	8	9	13	23
% of time dried in fall			33%	15%	3%	3%	39%	61%
Oct. 15	spring		8	8	8	11	15	24
% of time dried in fall			0%	0%	0%	3%	9%	30%

Commercial Wheat

Harvest Date	Dry Date		Moisture Content % 16	17	18	19	20	22
August 15	fall	100%	9	9	10	10	17	34
		97%	6	7	8	9	17*	34*
		94%	5	6	7	9*	17*	34*
		90%	5	5	6	9*	17*	34*
	spring		6	6	7	9	17	34
% of time dried in fall			97%	94%	94%	97%	100%	100%
Sept. 1	fall	100%	10	11	12	13	15	21
		97%	8	10	10	12	13	21
		94%	7	9	10	11	13*	21
		90%	7	8	9	10	13*	21*
	spring		7	8	8	8	13	21
% of time dried in fall			94%	91%	88%	76%	97%	100%
Sept. 15	fall	100%	19	23	28	30	32	37
		97%	17	22	23	24	25	27
		94%	13	13	16	17	20	27
		90%	10	12	15	16	17	26
	spring		8	8	8	8	9	18
% of time dried in fall			76%	73%	52%	33%	15%	88%
Oct. 1	spring		8	8	8	8	8	15
% of time dried in fall			33%	15%	3%	3%	0%	48%
Oct. 15	spring		8	8	8	8	8	16
% of time dried in fall			3%	0%	0%	0%	0%	0%

Barley

Harvest Date	Dry Date		Moisture Content % 16	18	20	22
August 15	fall	100%	16	16	18	40
		97%	9	12	18*	40*
		94%	8	10	18*	40*
		90%	7	9	18*	40*
	spring		7	9	18	40
% of time dried in fall			88%	88%	100%	100%
Sept. 1	fall	100%	19	19	24	30
		97%	16	19	19	27
		94%	14	17	18	27
		90%	13	16	17	27*
	spring		13	13	13	27
% of time dried in fall			91%	85%	85%	97%
Sept. 15	fall	100%	35	45	50	**
		97%	29	39	45	47
		94%	24	30	31	37
		90%	20	25	30	35
	spring		13	13	13	17
% of time dried in fall			73%	64%	45%	55%
Oct. 1	spring		13	13	13	17
% of time dried in fall			45%	24%	6%	15%

Canola (Rapeseed)

Harvest Date	Dry Date		Moisture Content % 10	11	12	13	14	15
August 15	fall	100%	16	16	16	16	17	28
		97%	13	13	13	13	15	28*
		94%	10	10	11	13*	15*	28*
		90%	7	8	9	13*	15*	28*
	spring		7	7	7	13	15	28
% of time dried in fall			88%	85%	76%	97%	97%	100%
Sept. 1	fall	100%	26	26	26	27	27	30
		97%	19	19	19	19	19	20
		94%	13	17	17	17	17	20*
		90%	13	14	15	16	17	20*
	spring		12	12	12	12	16	20
% of time dried in fall			85%	82%	79%	70%	85%	97%
Sept. 15	spring		12	12	12	12	12	14
% of time dried in fall			55%	39%	39%	33%	30%	36%
Oct. 1	spring		12	12	12	12	12	12
% of time dried in fall			24%	24%	15%	15%	9%	6%

* Lower airflows are possible for this condition, but a risk of spoilage would be introduced. See your local agricultural engineer for details.

** Airflow rates would be excessive for this condition.

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Table 3A is based on computerized drying simulations using Manitoba weather data from Winnipeg, Brandon and Dauphin for the years 1953 to 1985. **A fully perforated floor and a level grain surface are assumed. If either of these conditions are not met the airflow rates must be adjusted.** Contact your local agricultural engineer for details.

The airflow rates for seed wheat are based on a germination reduction of 10 per cent or less, and the rates for commercial wheat are based on the preservation of the milling quality. The rates for barley and canola (rapeseed) are based on an acceptable drop in germination levels. The final moisture contents were 14.5 per cent for wheat, 14.8 per cent for barley and 9.0 per cent for canola (rapeseed). The "fall" dry dates indicate airflow rates that would dry the grain in fall in 100, 97, 94 or 90 per cent of the years simulated. The "spring" dry dates indicate airflow rates that would dry the grain by June 1 of the following year. The "per cent of time dried in fall" indicates the likelihood that the spring airflow rates would complete the drying in fall.

Example: Canola (Rapeseed) at 12 per cent harvested on September 1.

To complete drying every year by November 15 would require an airflow rate of 26(L/s)/m³. An airflow rate of 12 (L/s)/m³ would complete drying by June 1 in every case, and would finish drying by November 15 in 79 per cent of the years.

CAUTION: EVEN WHEN THE RECOMMENDED AIRFLOW RATES ARE USED, THE GRAIN SHOULD BE CHECKED EVERY DAY OR TWO FOR ANY EVIDENCE OF MOLD, CRUSTING, HEATING OR OTHER SPOILAGE INDICATORS.

TABLE 3B

Recommended minimum airflow requirements [(L/s)/m³] for Manitoba using a fully perforated floor and a level grain surface

Corn

Harvest Date	Moisture Content % 20	22	24	26	28
September 15	10		29		117
October 1	8		22		49
October 15	8	13	20	25	52
November 1	8		12		20

Table 3B is based on computerized drying simulations using Winnipeg weather data for the years 1961 to 1970. The final moisture content was 15.5 per cent. The airflow rates given would complete drying in the spring following the harvest year.

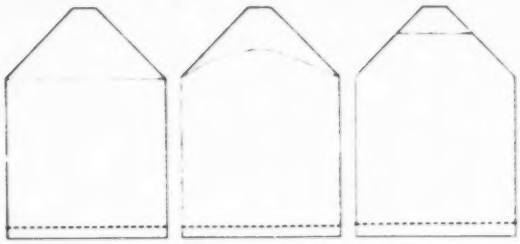
Management of Unheated Air Drying Systems

Fine material and broken grain increases airflow resistance, which reduces total airflow. Screening this material out will speed up the drying process. Since the fines tend to accumulate in the centre of the bin, unloading some grain from the centre when the bin is full will make the airflow more uniform.

Keeping the grain level will also help to promote uniform airflow. Grain spreading devices can be used to distribute the grain, but some additional hand levelling may still be needed. The use of a grain spreader helps to distribute the fines throughout the bin but it also packs the grain, thus increasing the resistance to airflow and increasing drying time. If a spreader is not used, some grain should be re-

moved from the centre of the bin after filling. This reduces the amount of grain to be moved while levelling, and removes some of the fine material.

There is a great temptation to leave the grain peaked up in the centre of the bin because of the extra work involved in levelling, and to gain the additional storage space under the roof cone. This does, however, substantially extend the time required to finish drying, and in some cases may result in grain spoilage near the top of the cone. Figure 11 shows the increased volume of grain and the increased drying times required as determined in one field test. A seven per cent increase in grain volume increased the drying time by 50 per cent, and a 10 per cent increase in grain volume increased the required drying time by 80 per cent.



STORAGE VOLUME	1.0	1.07	1.10
REQUIRED DRYING TIME	1.0	1.5	1.8

Figure 11. Effects of Grain Levels on Storage Volume and Required Drying Time.

The fan should be started as soon as the grain covers the drying floor, and operated continuously until drying is completed or the grain temperature drops to 0°C. The fan should not be shut off during periods of rainy weather and high humidity in the fall unless the conditions in Table 2 are met. Continuous fan operation reduces the time for the drying front to move through the grain, and helps reduce the rate of spoilage by keeping the temperature low. Even if some rewetting occurs at the bottom, this moisture will quickly be removed by operating the fan for a few days with fair weather conditions. The fan may be stopped when the grain temperature throughout the bin drops to 0°C or when all the grain is at a safe storage moisture content. After the fan is turned off, the intake should be covered to prevent air currents from passing through the grain. The cover will also prevent rodents from entering the bin.

During the winter the top 50 to 100 cm of the grain should be checked periodically for moisture build-up (particularly near the centre) or an increase in grain temperature. All grain temperatures should be recorded. If there is any increase in temperature, the fan should be operated until all the grain is at 0°C or lower.

In spring, if additional drying is necessary, the fan should be started when the average daily temperature exceeds 5°C and run until all the grain is dry. If there is any evidence of grain heating or spoilage during the unheated air drying process, the grain should be removed from the bin and dried with a heated air dryer.

Supplemental Heat

The drying rate of an unheated air drying system is determined primarily by the amount of air that is moved through the grain. The use of supplemental heat will increase the drying rate but will also increase the likelihood of spoilage if insufficient airflow is used. The heat picked up by the air as it passes over the motor and/or the heat of compression produced by the fan will usually add 1 to 2°C to the temperature of the air. This reduces the relative humidity by approximately five to 10 per cent and typically results in some overdrying of the grain. In most cases the grain below the drying zone will be seriously over-dried if more heat is added. This reduces the total marketable weight of the grain.

Total energy requirements for drying are usually increased when supplemental heat is added. If additional energy is supplied to a bin, it is generally more efficient to use it for increased fan capacity rather than for supplemental heat. Increased airflow provides more advantages (better reliability, higher drying capacity, more uniform drying and lower energy requirements) than adding supplemental heat.

Large solar collector areas are required to provide an average temperature rise of even 1 to 2°C from solar heat at high airflows. The small amount of energy obtained from solar collectors in fall does not justify the cost of a collector for grain drying. Also, since the addition of any heat normally results in reduced marketable weight due to increased overdrying, the use of solar collectors for grain drying is usually uneconomical.

In situations where the grain will not dry in fall without adding heat, and the grain needs to be sold before spring, the addition of up to 5°C may be warranted. If possible, the overdried grain at the bottom should then be mixed with damp grain at the top to minimize the losses due to overdrying.

3. DRYERATION

A typical heated air dryer uses heating followed by rapid cooling of the grain in the dryer before transferring to storage. Dryeration (Figure 12) modifies this high-speed drying and cooling process by transferring the hot grain to a cooling bin for slower cooling after a waiting period. In-dryer cooling is eliminated. After cooling in the bin, the grain may be transferred to another storage bin. Dryeration provides three advantages over heated air drying with in-dryer cooling:

- increased dryer capacity
- reduced fuel consumption
- less danger of grain quality reduction

Grain is delivered hot from a heated air dryer at two to three per cent above the final desired moisture content to a dryeration or cooling bin. There it is "tempered" (stored without airflow) for eight to 10 hours before being slowly cooled. The drying capacity of the heated air dryer is increased since it is no longer used for cooling. A burner can be added to the cooling section of a continuous flow dryer to use the entire dryer column for heating the grain. In a batch dryer the cooling time is eliminated.

Immediately after heated air drying, the outside of the kernel is drier than the centre. During the tempering process the moisture content throughout the kernel has time to equalize. Two to three percentage points of moisture can then be removed during the slow cooling process that fol-

lows the tempering period. By contrast, little water is removed during rapid in-dryer cooling. Because the grain can be removed from the heated air dryer at a higher moisture content prior to cooling, the drying capacity is increased. Also the heat contained in the grain is more effectively used for removing water during cooling with dryeration, so that less fuel is used. Approximately one per cent of moisture is removed for every 15°C drop in grain temperature during dryeration cooling.

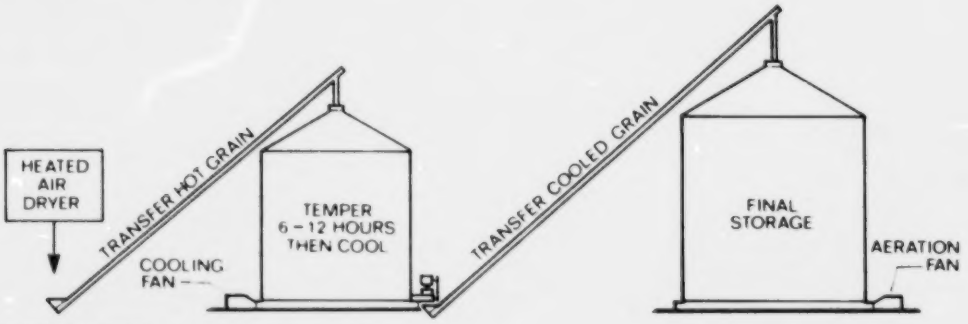


Figure 12. Dryeration Process.

When using dryeration, the kernel stresses developed in the final stages of heated air drying and cooling are minimized. Stress cracking and kernel damage is reduced, particularly with corn or other large seeded crops. Grain dried using this process is less susceptible to damage during subsequent handling operations.

When using dryeration, the drying air temperature in heated air dryers may be increased slightly, since the grain is discharged at a higher moisture content and is in the dryer for a shorter period of time. Increasing the drying air temperature increases the dryer capacity and slightly improves the fuel efficiency of the heated air dryer. **CAUTION: IF DRYING AIR TEMPERATURE IS INCREASED, THE GRAIN QUALITY (TEST WEIGHT, MILLING QUALITY, GERMINATION AND/OR STRESS CRACKING) MUST BE CHECKED TO ENSURE THAT SATISFACTORY QUALITY IS BEING MAINTAINED.**

The amount of fuel saved and the increase in dryer capacity when using dryeration depends on weather conditions, grain temperatures and moisture contents. Typically, a 20 to 40 per cent savings in energy and a 50 to 75 per cent increase in dryer capacity result. Actual energy savings and capacity increases depend primarily on the initial grain moisture content. Larger percentage increases in capacity and energy savings occur when drying lower moisture grain.

After cooling is completed, the grain must be transferred from the dryeration bin to aerated storage if the dryeration bin does not have a fully perforated floor. During the tempering period condensation can occur in the grain next to the bin wall. This could cause grain spoilage if the grain is not mixed by transferring to another bin. If the cooling bin has a fully perforated floor, the grain may be left in the same bin and any damp spots dried out by unheated air drying.

Management of Dryeration Systems

A separate cooling bin (or bins) is necessary for dryeration. The physical arrangement of the dryer and the cooling bins should facilitate switching from one bin to another and transferring of cooled grain to final storage. Ideally, two or more cooling bins should be available, each holding a minimum of 12 hours of dryer capacity.

With two cooling bins the following procedure is used. Hot grain is delivered to the cooling bin at two to three per cent above "dry" and allowed to temper with the fan turned off. After the first hot grain delivered to the bin has tempered for about eight to 10 hours, the cooling fan is turned on. The dryer discharge is then switched to the second cooling bin. Cooling is completed in the first bin in about eight to 10 hours and the grain is transferred to final storage. During this time the second bin receives hot grain for about eight to 10 hours and the same procedure is repeated. This allows 16 to 20 hours of dryer operating time per day.

If only one cooling bin is used it should be large enough to hold several days dryer capacity. Hot grain is delivered to the bin, allowed to temper and then cooled daily. Each day more hot grain is added to the bin. Again, to provide the maximum benefit from dryeration, the cooling fan should be turned on and off to provide eight to 10 hour tempering periods for all hot grain. Considerable checking of the cooling rate for the fan-bin system is required in order to determine when the fan(s) should be turned on and off.

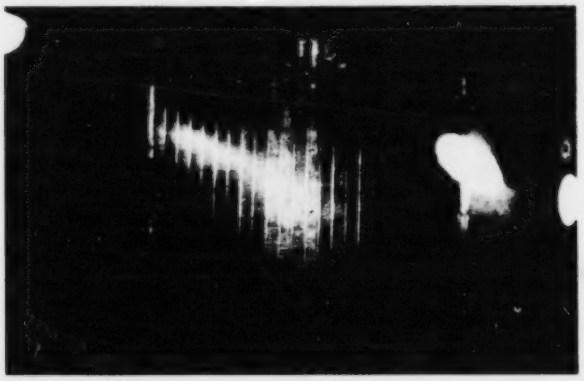
Cooling bins should have at least 40 per cent of the floor area perforated to ensure a reasonably good airflow distribution. A fully perforated floor is recommended. An airflow rate of five to 10 $(L/s)/m^3$ is normally used for cooling bins. Lower airflows may remove more moisture because of the slower cooling rate but increase the risk of spoilage before cooling is completed.

For dryeration, the air should be forced upward through the grain so that it is exhausted at the top. If downward airflow were used, the grain in the lower part of the bin would not be cooled soon enough and could be in danger of spoilage. Also, the last grain put into the bin would not have had sufficient tempering time for maximum moisture removal. With upward airflow, heavy condensation on the roof and upper portions of the bin walls may occur particularly in cold weather. When the cooled grain is transferred from the bin, the small quantity of wet grain around the walls is blended with the remaining grain in the bin so that no storage problems result. If the cooling bin has a fully perforated floor drying can be completed with unheated air and the grain left in the bin for final storage.

Careful monitoring of grain conditions is required. Accurate checks on moisture content of the grain before and after cooling and on temperatures of hot grain discharged from the dryer and cooled grain in the bins are necessary.

A bin probe thermometer can be used to monitor the cooling progress in the bin. Stationary temperature sensors mounted on cables are highly recommended for monitoring temperatures in bins of 500 m^3 or larger. Be sure to check the grain temperature in the top centre of the bin since it is normally the last to cool. Do not stop the fan as long as there is warm grain in the bin.

CAUTION: BE CAREFUL WHEN INSPECTING BINS DURING GRAIN COOLING. THE HOT, MOIST AIR CAN BE HAZARDOUS TO BREATHE. DO NOT CLIMB INTO THE BIN UNDER THESE CONDITIONS. EXERCISE CARE WHEN LOOKING THROUGH THE TOP ENTRANCE DOOR INTO THE BIN SINCE METAL SURFACES MAY BE SLIPPERY AND EYEGLASSES MAY FOG UP.



Partially Perforated Floor

4. IN-STORAGE COOLING

In-storage cooling is very similar to dryeration, (see Figure 13) with one important difference. When the hot grain is delivered from the dryer to a cooling bin with a partially perforated floor, the fan is started immediately rather than allowing the grain to temper. The reason for eliminating the tempering period is to reduce or eliminate the condensation on the roof and walls. This allows the grain to be stored in the cooling bin rather than needing to be transferred to another bin for storage. Although dryeration has advantages over in-storage cooling in terms of energy savings, dryer capacity, and grain quality, in-storage cooling may be an attractive alternative for bins with partially perforated floors, since it allows them to be used for both cooling and final storage. The minimum perforated floor area for in-storage cooling bins is 40 per cent of the total floor area.

Because the grain is cooled at a slower rate, the heat in the grain is used more efficiently than it would be if cooling was done in the heated air dryer. There is typically a one per cent drop in moisture content during in-storage cooling. The biggest advantage of in-storage cooling as compared to cooling in a heated air dryer is the significant increase in capacity which occurs when the cooling cycle in a batch dryer is eliminated or when the cooling section in a continuous flow dryer is used for heating.

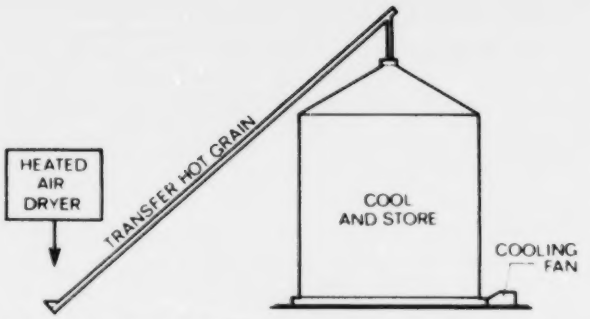


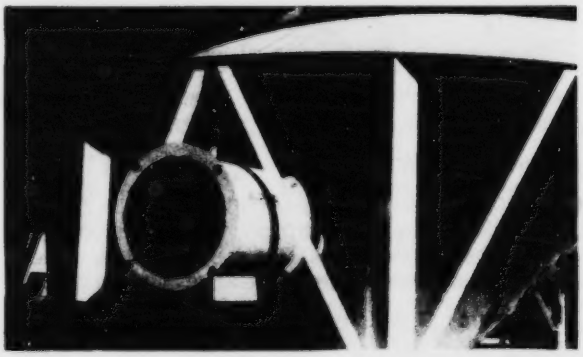
Figure 13. In-Storage Cooling Process

Management of In-Storage Cooling Systems

For in-storage cooling the fans must cool the grain as quickly as it is dried. The required airflow is the same as for dryeration — about five to 10 (L/s)/m^3. Start the fan as soon as hot grain is delivered to the bin and continue to run it until all the grain is cooled. Once the grain is cooled to the outside temperature, the fan is operated as necessary to lower the grain temperature to 0°C in the late fall. Procedures for fan operation during subsequent storage periods are described in the section on aeration.

5. HOPPER BOTTOM BINS

Hopper bottom bins are commonly used for aerating damp grain prior to being dried in a heated air dryer, and for cooling hot grain that has been dried in a heated air dryer. Hopper bottom bins are used for these situations because of the convenience of labour-free cleanout. However, installing an adequate aeration system is often very difficult. It is hard to provide enough perforated floor area and to support it adequately without restricting the flow of grain out of the bin. For example, a bin with a capacity of 60 m^3 requires over 2 m^2 of perforated floor area for cooling. It is also extremely difficult to design a practical system that will provide a uniform airflow to all parts of the bin. A higher airflow must therefore be used to compensate for the non-uniformity. This will result in higher power requirements than would be needed for the same volume of grain in a flat bottom bin. Because of the higher costs as compared to flat bottom bins, the use of hopper bottom bins for unheated air drying may be uneconomical. Comparisons of the drying uniformity and other performance factors of various commercial aeration systems for hopper bottom bins are available in test reports from the Prairie Agricultural Machinery Istitute.



Aeration in a Hopper Bottom Bin

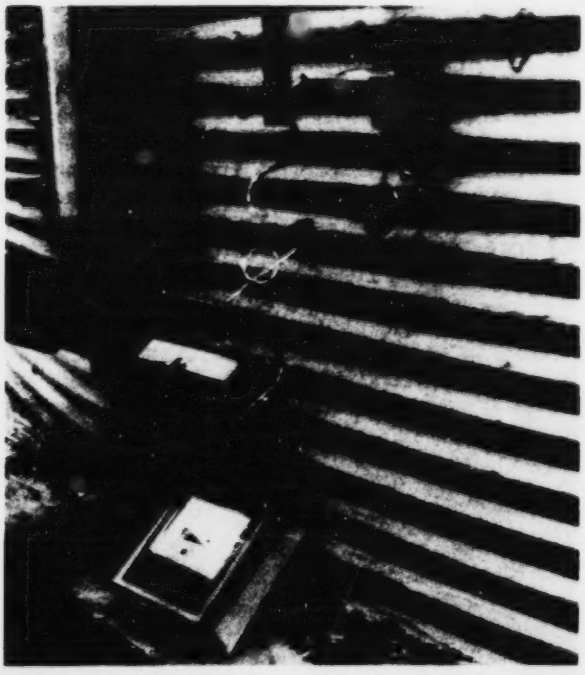
6. EQUIPMENT

Screening and Spreading

Fine material, weed seeds and other foreign material can interfere with air flow. These normally accumulate at or near the centre core of the bin which becomes a prime location for increased mold and insect activity. This may cause localized heating and further grain deterioriation because of delayed cooling and/or higher moisture content.

To reduce potential storage problems caused by foreign material, any of the following practises may be used:

- Screen the grain to reduce the amount of foreign material
- Use a spreader to distribute the foreign material more uniformly throughout the storage. This helps provide more uniform airflow during aeration or drying. The packing effect produced by the spreader will increase the grain's resistance to airflow and reduce the overall airflow through the grain mass. An offsetting advantage is that five to 10 per cent more grain can be stored in the bin, due to packing.
- Unload some grain from the centre to remove some of the accumulated fines. This results in a more uniform airflow through the grain because of less variation in airflow resistance.



Grain Temperature Monitor

Stored Grain Monitoring

To properly manage stored grain the operator must be able to obtain samples, determine moisture contents, and monitor grain temperatures. Records of moisture content and grain temperatures should be kept.

To determine moisture content and general grain conditions, sample grain at various levels using a deep bin probe at the locations indicated in Figure 6. An accurate moisture tester is also needed. Test reports on many of the available grain moisture testers are available from the Prairie Agricultural Machinery Institute. Readings on freshly dried grain, warm or hot grain, excessively cold grain, etc., are frequently inaccurate. Calibrate your tester under these conditions by checking readings with the local elevator or with other more accurate testers.

Temperature sensors permanently installed in bins are valuable in monitoring storage temperatures and aeration progress. For bins without sensors, use temperature probes for checking the temperature at different locations. Aeration progress can be determined and trouble spots can be located with temperature monitoring if it is done in a systematic and conscientious manner.

Perforated Floors, Fans, Transitions and Vents

Unheated air drying involves moving large quantities of air at moderately high pressures, so the selection and matching of equipment is extremely important. Minimizing air losses and pressure drops in the components is a prime consideration.

There are two main types of perforated flooring material available. They are commonly referred to as cereal and canola (rapeseed) flooring. The cereal flooring has larger openings and is able to pass more air without a significant pressure drop. The minimum areas of perforated flooring for various airflows for both floor types are given in Tables 7 and 8.

Partially perforated floors are sometimes used in unheated air drying facilities. There are several disadvantages to using anything less than a fully perforated floor. There is a higher pressure requirement with a partial floor, which means a larger fan size is needed. Field tests have shown that if 40 per cent of the total area is perforated flooring, 10 per cent more fan power is required; if 25 per cent of the total area is perforated flooring, 30 per cent more fan power is required. The time required to complete drying is substantially increased if a partially perforated floor is used. Depending on the layout and the amount of perforated flooring, a partial floor may require 25 to 100 per cent more fan operating time because of the non-uniform airflow produced. This means that a higher airflow rate needs to be used to compensate for the non-uniformity of the airflow patterns, which in turn means a higher fan power requirement. In most cases the money spent on the extra purchase and operating costs of the fan would be better spent on providing a fully perforated floor. If a partially perforated floor is used for unheated air drying, the perforated floor area should be at least 40 per cent of the total, and the airflow rates given in Table 3 must be increased. Contact your local agricultural engineer for the appropriate adjustment.

Many different types of fans are available for unheated air drying. Each type is suitable for a specific pressure range. Figure 14 shows the characteristics of several fan types of the same power made by one manufacturer. The axial fan produces the highest airflow and is the most economical at low static pressures (below 900 Pa). At the highest pressures (above 1800 Pa) the high speed centrifugal produces the highest airflow. The other two fan types are most suitable at intermediate pressures. The selection of a fan type therefore depends primarily on the pressure at which it will operate. Detailed performance information on most of the

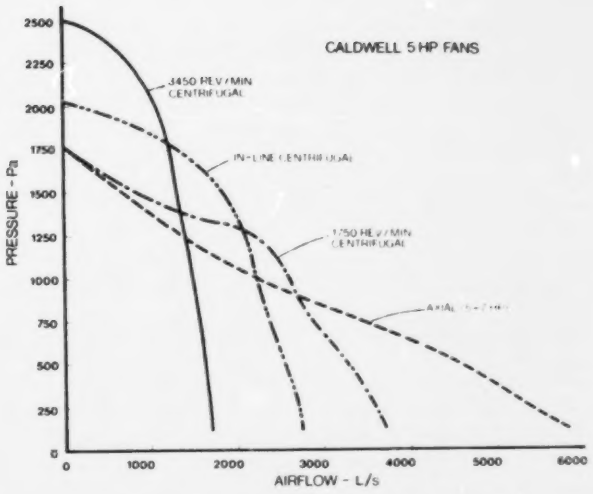


Figure 14. Performance Characteristics of Various Fan Types.

common fans available is contained in the publication "Fan Test Results" and in Prairie Agricultural Machinery Institute test reports. A summary of average fan characteristics is given in Table 6. These averages can be used to determine an approximate fan power requirement for a given pressure and airflow. In some cases the noise level produced by the fan is also an important consideration. Generally the axial fans are the noisiest and the low speed centrifugals are the quietest. Positioning of the fan on the bin should take the noise factor into account. Placing the fan on the far side of the bin, away from the farm residence is usually the best choice.

Static pressure sensors are useful for determining maximum acceptable grain depths for unheated air drying, particularly when axial fans are used. Since there is always some variation from one bin of grain to another, the actual static pressure encountered cannot be predicted with absolute certainty. By monitoring the static pressure under the floor as the bin is being filled, and referring to the fan performance information, the maximum depth of grain for a desired airflow can be determined. There are various commercial dial and U-tube static pressure gauges (manometers) available, and plans for home built U-tube manometers can also be obtained.

Transitions can cause considerable pressure loss and air loss if improperly designed or installed. The outlet area of the transition must be adequate for the airflow produced by the fan. The shape should provide a smooth airflow route without any abrupt direction changes. If any bin stiffeners need to be cut to install the transition, suitable alternative support must be provided to prevent bin wall collapse. The transition must be properly sealed at the fan and bin ends to prevent air losses. Full details on transition design and selection are available in the factsheet "Transitions for Delivering Air to Grain Bins".

Air losses can also occur around the base of the bin, at panel joints, and through entrance doors and auger ports. Careful sealing of these areas during construction and annual inspections are needed to ensure minimum air losses. Doors and auger ports may require yearly sealing with plastic sheeting, plywood or tape.

Adequate roof vent areas must be provided to prevent pressure losses through the air exhausts. The minimum vent areas for various airflows are shown in Table 7. Most bins have roof entrance doors and/or filler hatches that can be left open for air exhaust. Some also have openings around the eaves. All of these areas can be considered when determining if additional roof vents are required. On many of the smaller bins, the existing openings will be found to be adequate. Weatherproof vents should be considered for greater convenience.

7. FAN SELECTION AND SYSTEM DESIGN

TABLE 4

Summary of Basic Recommendations for Drying and Cooling Processes

Process	% above "dry"*	Recommended airflow rates (L/s)/m³	Recommended Minimum perforated floor area	Transfer for final storage
Aeration	0	1-2	15%	No
Unheated Air Drying	See Table 3		100	No
Dryeration	2-3	5-10	40	Yes
			100	No
In-Storage Cooling	1	5-10	40	No

* *% above "dry" is the number of moisture percentage points above "dry" at which the grain is placed into the bin. Example: For dryeration, wheat is placed into the bin at up to 17% moisture (14.5 + 2.5 = 17%).*

Satisfactory performance of an air handling system depends on the selection of proper equipment, adequate sizing, proper installation, and good management. Three requirements must be met to ensure proper performance:

1) Selection of a fan or combination of fans that deliver the required air flow at the necessary static pressure
2) Proper sizing and arrangement of the perforated duct surface area or perforated floor area to deliver the air uniformly
3) Proper sizing (cross-sectional flow area) of the ducts, fan transition, and bin exhaust vents.

The dimensions and the capacity of the grain bin to be used are necessary for designing an airflow system. Table 5 gives this information for some of the common steel bins used in western Canada.

The required airflow rates also need to be known for the desired process. These are given for aeration, in storage cooling and dryeration in Table 4 and for unheated air drying of wheat, barley, canola (rapeseed) and corn in Tables 3A and 3B.

Airflow resistance for various grains is also needed. Figures 15 to 20 provide this information for wheat, barley, canola (rapeseed), sunflowers, corn and flax.

Other information needed is the performance characteristics of various fans. An average of the outputs of various common axial flow and centrifugal fans is given in Table 6. Actual characteristics of various fans are available in the Manitoba Agriculture publication "Fan Test Results" or

Prairie Agricultural Machinery Institute test reports, and should be used in preference to the averages given in Table 6.

Once the fan has been selected, the duct area, perforated floor area and the exhaust vent area must be determined. These can be taken directly from Table 7 or 8.

Example 1

Wheat to be aerated in a Butler 2422 bin with a 15% perforated floor.

Eaves height = 6.7 m Volume = 280 m^3 (Table 5)
Airflow rate = 1.5 (L/s)/m^3 (Table 4)
Airflow required = 1.5 × 280 = 420 L/s
Pressure = 250 Pa (Figure 15) × 1.5 = 375 Pa
Fan required = 1 HP axial flow - 14" diameter (Table 6)
Minimum duct area = 0.06 m^2 (Table 7)
Check Table 7 to ensure that the perforated floor area is adequate.
1.8 m^2 needed (cereal floor)
0.15 × 41.9 = 6.3 m^2 provided.
Minimum roof vent area = 0.08 m^2 (Table 7)

Example 2

Barley to be cooled in storage in a Westeel 196 bin with a 40% perforated floor.

Eaves height = 4.6 m Volume = 124 m^3 (Table 5)
Airflow rate = 8 (L/s)/m^3 (Table 4)
Airflow required = 8 × 124 = 1000 L/s
Pressure = 650 Pa (Figure 16) × 1.1 = 720 Pa
Fan required = 3 HP axial flow — 18" diameter (Table 6) or 1.5 HP in-line centrifugal.
Check Table 7 to ensure that the perforated floor area is adequate.
4.4 m^2 needed (cereal floor)
0.40 × 26.4 = 10.6 m^2 provided.
Minimum roof vent area = 0.20 m^2 (Table 7)

Example 3

Commercial wheat to be unheated air dried from 18% in a Behlen 22 bin, harvested September 1, fall drying, fully perforated floor.

Eaves height = 6.1 m Volume = 215 m^3 (Table 5)
Airflow rate (100% in fall) = 12 (L/s)/m^3 (Table 3)
Airflow required = 12 × 215 = 2580 L/s
Pressure = 2400 Pa (Figure 15)
Fan required = 15 HP centrifugal 3450 rev/min (Table 6)
Minimum duct area = 0.34 m^2 (Table 7)
Minimum roof vent area = 0.52 m^2 (Table 7)

Example 4

Corn to be dryeration cooled in a Westeel 2406 bin with spreader.

Eaves height = 6.8 m Volume = 281 m^3 (Table 5)
Airflow rate = 8 (L/s)/m^3 (Table 4)
Airflow required = 8 × 281 = 2250 L/s
Pressure = 850 Pa (Figure 19) Multiply by 2 for spreader.
2 × 850 = 1700 Pa
Fan required = 10 HP centrifugal — 3450 rev/min (Table 6)
Minimum duct area = 0.30 m^2 (Table 7)
Minimum perforated floor area = fully perforated for storage *or* greater of —

a) 10 m^2 (Table 7) (cereal floor)
b) 40% of 41.8 (Tables 4 & 5) = 16.7 m^2 *if grain is to be transferred*

Minimum roof vent area = 0.45 m^2 (Table 7)

Example 5

Canola (Rapeseed) to be unheated air dried from 13% in a Chief Westland 6-6 bin with a square perforated floor covering 50% of the total floor area. Harvest date August 15. Note: A fully perforated floor is recommended for unheated air drying.

Eaves height = 5.0 m Volume = 127 m^3
Airflow rate (minimum) = 13 (L/s)/m^3 (Table 3)
Airflow required = 13 × 127 = 1650 L/s
Pressure = 3200 Pa (Figure 17)
This pressure and airflow is higher than can be produced by common agricultural fans.
Try reducing depth of canola (rapeseed) to 4.0 m (102 m^3 volume)
Airflow required = 13 × 102 = 1325 L/s
Pressure = 2000 Pa
Fan required = 7.5 HP 3450 rev/min centrifugal (Table 6)
Minimum duct area = 0.18 m^2 (Table 7)
Minimum roof vent area = 0.27 m^2 (Table 7)
Minimum perforated floor area required = 17.7 m^2 [canola (rapeseed) floor] (Table 7)
The actual perforated floor area is 50% × 25.2 = 12.6 m^2, which is inadequate. A totally perforated floor should be used.

Computer Program

The entire design procedure is available in a computer program which calculates the airflow and static pressure requirements for various grains, airflow rates, bin diameters and grain depths. It will also select suitable fans by make and model. The program can predict airflow rates for any given fan, bin and grain combination, and simulate drying for wheat, barley and canola. The computer program can be accessed at any of the engineering offices in Manitoba as follows:

Dauphin —	638-9111	Arborg —	376-5212
Brandon —	728-5724	Beausejour —	268-1411
Portage —	857-9711	Winnipeg —	945-3862

Conversion Factors

1 inch of water = 250 Pa (pascals)

1 cubic foot per minute = 0.47 L/s (litres per second)

100 bushels = 3.6 m^3 (cubic metres)

1 cubic foot per minute per bushel = 13 (L/s)/m^3 (litres per second per cubic metre)

1 foot = 0.3 m (metres)

1 square foot = 0.1 m^2 (square metres)

Acknowledgements

We gratefully acknowledge the contribution of Agriculture Canada under Project 32103 of the Agri-Food Agreement for the information contained in Table 3A. The research and development of the basic data for Tables 3A and 3B was conducted by Dr. W.E. Muir, C.I. Kitson and D.B. Sanderson of the Agricultural Engineering Department, University of Manitoba. We also acknowledge the background information provided by H.A. Cloud and R.V. Morey of the University of Minnesota. The design procedure and worksheet was originally developed by H.P. Harms.

TABLE 5

Grain Bin Dimensions and Volumes

Make	Model	Diameter (m)	Floor Area (m^2)	Height to Eaves (m)	Volume to Eaves Height (m^3)
Behlen Vertical	12	3.7	10.8	3.1	33
				4.6	49
	16	4.8	18.3	3.1	56
				4.6	84
				6.1	112
	22	6.7	35.3	3.1	108
				4.6	161
				6.1	215
				7.6	269
				9.1	323
	27	8.2	52.5	3.1	160
				4.6	240
				6.1	320
				7.6	400
				9.1	480
				12.2	641
	34	10.2	81.5	3.1	248
				4.6	373
				6.1	497
				7.6	621
				9.1	745
				12.2	993
Horizontal	H-12	3.7	10.9	3.9	42
				5.0	55
	H-16	4.9	18.4	3.9	72
				5.0	93
				6.2	114
	H-22	6.7	35.5	3.9	138
				5.0	179
				6.2	219
				7.3	260
	H-27	8.2	52.8	3.9	205
				5.0	265
				6.2	326
				7.3	386
				8.4	444
				10.7	564
				13.0	685
	H-35	10.4	85.5	6.1	523
				8.4	719
				10.7	914
				13.0	1110

Make	Model	Diameter (m)	Floor Area (m^2)	Height to Eaves (m)	Volume to Eaves Height (m^3)
Brock	7-01504	4.6	16.4	3.3	54
	7-01505			4.1	67
	7-01506			4.9	81
	7-01507			5.7	94
	7-01508			6.6	107
	7-01804	5.5	23.7	3.3	78
	7-01805			4.1	97
	7-01806			4.9	117
	7-01807			5.7	136
	7-01808			6.6	155
	7-02104	6.4	32.3	3.3	107
	7-02105			4.1	133
	7-02106			4.9	159
	7-02107			5.7	185
	7-02108			6.6	212
	7-02109			7.4	238
	7-02110			8.2	264
	7-02404	7.3	42.1	3.3	139
	7-02405			4.1	173
	7-02406			4.9	208
	7-02407			5.7	242
	7-02408			6.6	276
	7-02409			7.4	310
	7-02410			8.2	344
	7-02706	8.2	53.2	4.9	262
	7-02707			5.7	305
	7-02708			6.6	348
	7-02709			7.4	392
	7-02710			8.2	435
	7-02711			9.0	478
	7-02712			9.8	521
	7-03006	9.1	65.6	4.9	323
	7-03007			5.7	377
	7-03008			6.6	430
	7-03009			7.4	483
	7-03010			8.2	537
	7-03011			9.0	590
	7-03012			9.8	643
	7-03306	10.1	79.4	4.9	391
	7-03307			5.7	456
	7-03308			6.6	520
	7-03309			7.4	585
	7-03310			8.2	650
	7-03311			9.0	714
	7-03312			9.8	778

TABLE 5
Grain Bin Dimensions and Volumes

Make	Model	Diameter (m)	Floor Area (m^2)	Height to Eaves (m)	Volume to Eaves Height (m^3)
Butler	1411	4.3	14.3	3.4	48
	1415			4.5	64
	1418			5.6	80
	1511	4.6	16.4	3.4	55
	1515			4.5	73
	1518			5.6	92
	1811	5.5	23.8	3.4	81
	1815			4.5	107
	1818			5.6	133
	1822			6.7	159
	2111	6.4	32.2	3.4	109
	2115			4.5	145
	2118			5.6	180
	2122			6.7	215
	2124			7.2	232
	2126			7.8	250
	2411	7.3	41.9	3.4	142
	2415			4.5	188
	2418			5.6	234
	2422			6.7	280
	2424			7.2	301
	2426			7.8	326
	2711	8.2	52.8	3.4	180
	2715			4.5	238
	2718			5.6	296
	2722			6.7	354
	2724			7.2	381
	2726			7.8	412
	3015	9.1	65.0	4.5	293
	3018			5.6	364
	3022			6.7	436
	3024			7.2	469
	3026			7.8	508
	3033			10.1	654
	3315	10.1	79.5	4.5	355
	3318			5.6	444
	3322			6.7	533
	3324			7.2	573
	3326			7.8	622
	3333			10.1	800

Make	Model	Diameter (m)	Floor Area (m^2)	Height to Eaves (m)	Volume to Eaves Height (m^3)
Chief Westland	4-4	3.8	11.2	3.4	38
	4-5			4.2	47
	4-6			5.0	56
	4-7			5.9	66
	5-3	4.7	17.5	2.5	44
	5-4			3.4	59
	5-5			4.2	74
	5-6			5.0	88
	5-7			5.9	103
	6-4	5.7	25.2	3.4	84
	6-5			4.2	106
	6-6			5.0	127
	6-7			5.9	148
	7-4	6.6	34.2	3.4	116
	7-5			4.2	143
	7-6			5.0	171
	7-7			5.9	200
	8-5	7.5	44.7	4.2	188
	8-6			5.0	224
	8-7			5.9	262
	9-5	8.5	56.5	4.2	237
	9-6			5.0	283
	9-7			5.9	332

TABLE 5

Grain Bin Dimensions and Volumes

Make	Model	Diameter (m)	Floor Area (m²)	Height to Eaves (m)	Volume to Eaves Height (m³)
Stormor	1300C	4.6	16.4	2.4	40
	1750C			3.3	53
	2100C			4.1	67
	2500C			4.9	80
	2900C			5.7	93
	1650C	5.5	23.6	2.4	58
	2200C			3.3	78
	2750C			4.1	97
	3300C			4.9	116
	4150C			5.7	135
	4700M			6.5	154
	5300M			7.3	173
	3350C	6.4	32.2	3.3	106
	3800C			4.1	132
	4400C			4.9	158
	5800C			5.7	183
	6700M			6.5	209
	7300M			7.3	235
	5500C	7.3	42.0	4.1	172
	6500C			4.9	206
	7500C			5.7	239
	8500M			6.5	273
	9500M			7.3	307
	10600M			8.1	341
	7000C	8.2	53.2	4.1	218
	8300C			4.9	261
	9600C			5.7	303
	10800M			6.5	346
	12100M			7.3	388
	13600M			8.1	431
	8600C	9.1	65.6	4.1	269
	10200C			4.9	322
	11700C			5.7	374
	13400M			6.5	427
	15100M			7.3	479
	16800M			8.1	532
	19500S			9.8	643
	24400S			12.1	801
	29400S			14.6	960
	9900C	10.1	79.4	4.1	326
	12800C			4.9	389
	14600M			5.7	453
	16200M			6.5	516
	18700M			7.3	580
	21000M			8.1	643
	23800S			9.8	778
	29200S			12.2	969
	35500S			14.6	1160

Make	Model	Diameter (m)	Floor Area (m²)	Height to Eaves (m)	Volume to Eaves Height (m³)
Westeel	144	4.2	13.9	3.1	43
	145			3.9	54
	146			4.6	65
	147			5.4	76
	148			6.2	87
	194	5.8	26.4	3.1	82
	195			3.9	103
	196			4.6	124
	197			5.4	143
	198			6.2	164
	1503	4.6	16.6	3.4	55
	1504			4.5	73
	1505			5.6	92
	1803	5.5	23.8	3.4	80
	1804			4.5	106
	1805			5.6	132
	1806			6.8	158
	1807			7.9	184
	2103	6.4	32.0	3.4	108
	2104			4.5	144
	2105			5.6	179
	2106			6.8	215
	2107			7.9	251
	2403	7.3	41.8	3.4	141
	2404			4.5	188
	2405			5.6	234
	2406			6.8	281
	2407			7.9	327
	2703	8.2	52.8	3.4	179
	2704			4.5	238
	2705			5.6	297
	2706			6.8	355
	2707			7.9	414
	3004	9.1	65.0	4.5	294
	3005			5.6	366
	3006			6.8	439
	3007			7.9	511
	3304	10.0	78.5	4.5	355
	3305			5.6	443
	3306			6.8	531
	3307			7.9	619
	3604	11.0	95.0	4.5	423
	3605			5.6	527
	3606			6.8	632
	3607			7.9	736

WHEAT

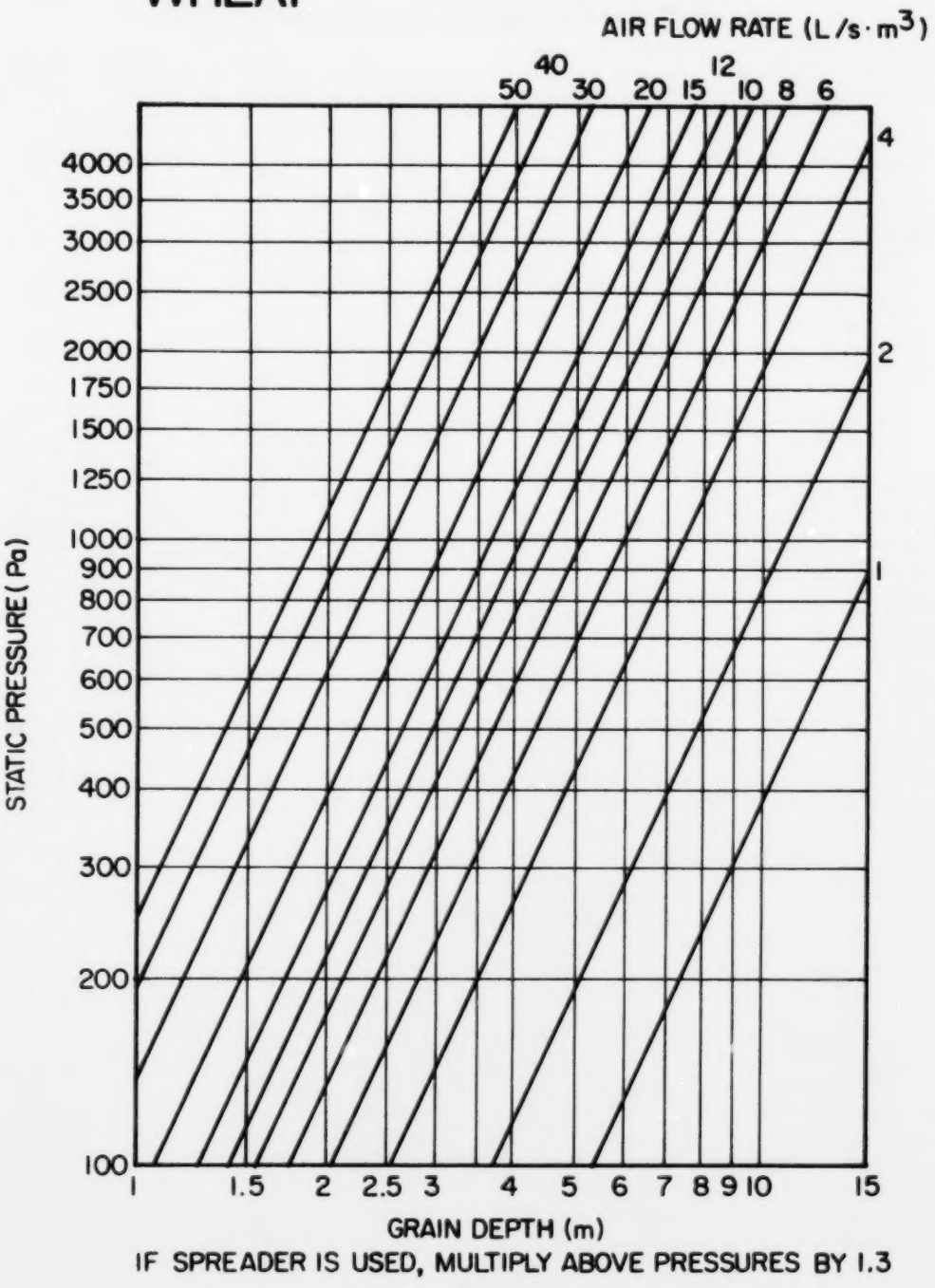


Figure 15 Airflow Resistance for Wheat on a Fully Perforated Floor

Note: If only a portion of the floor is perforated, multiply the above pressures by an appropriate factor from the table below.

% of floor area that is perforated	Multiply pressure by
40	1.1
25	1.3
15	1.5

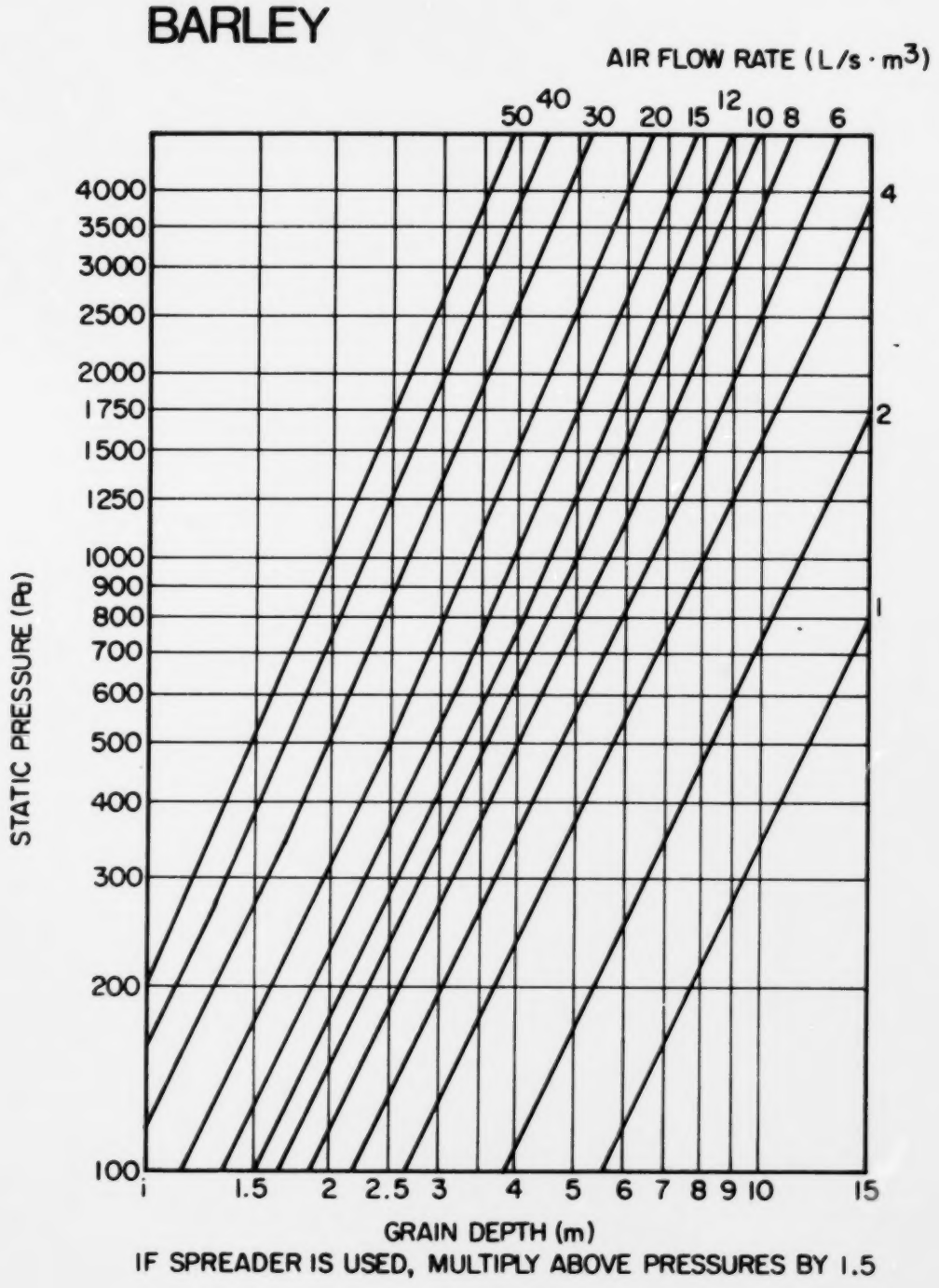


Figure 16 Airflow Resistance for Barley on a Fully Perforated Floor

Note: If only a portion of the floor is perforated, multiply the above pressures by an appropriate factor from the table below.

% of floor area that is perforated	Multiply pressure by
40	1.1
25	1.3
15	1.5

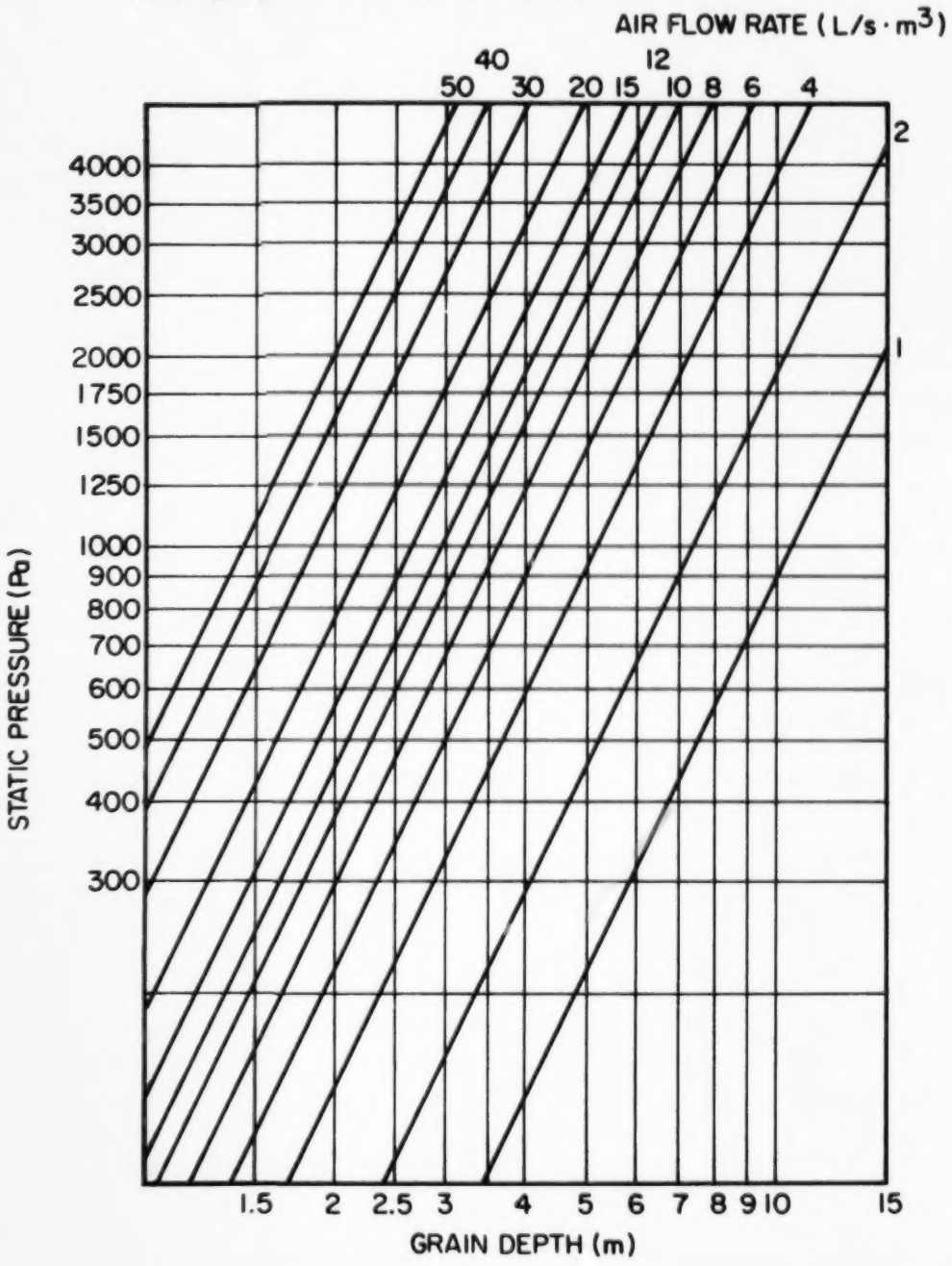


Figure 17 Airflow Resistance for Argentine Canola (Rapeseed) on a Fully Perforated Floor

Note: If only a portion of the floor is perforated, multiply the above pressures by an appropriate factor from the table below.

% of floor area that is perforated	Multiply pressure by
40	1.1
25	1.3
15	1.5

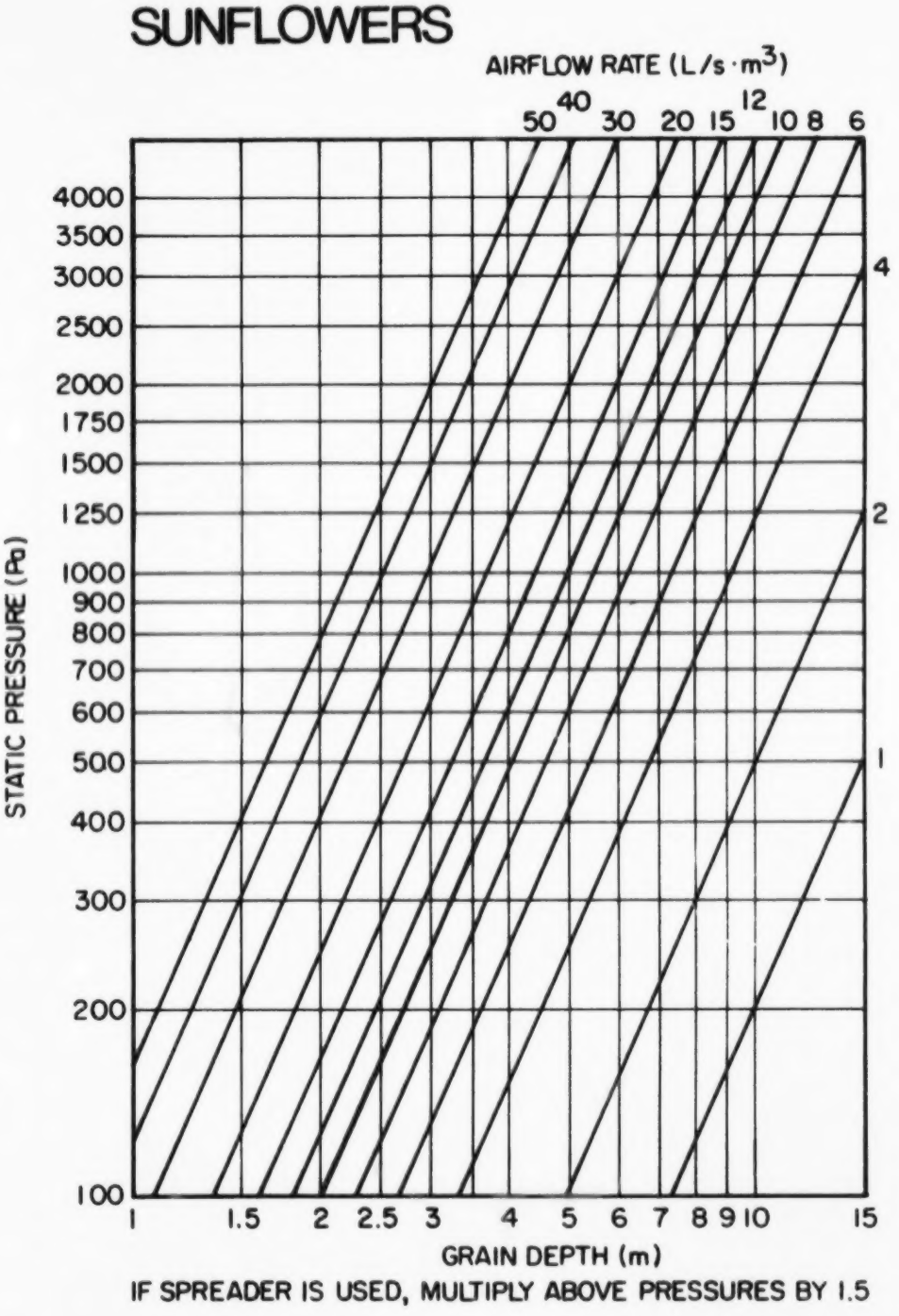


Figure 18 Airflow Resistance for Sunflowers on a Fully Perforated Floor

Note: If only a portion of the floor is perforated, multiply the above pressures by an appropriate factor from the table below.

% of floor area that is perforated	Multiply pressure by
40	1.1
25	1.3
15	1.5

CORN

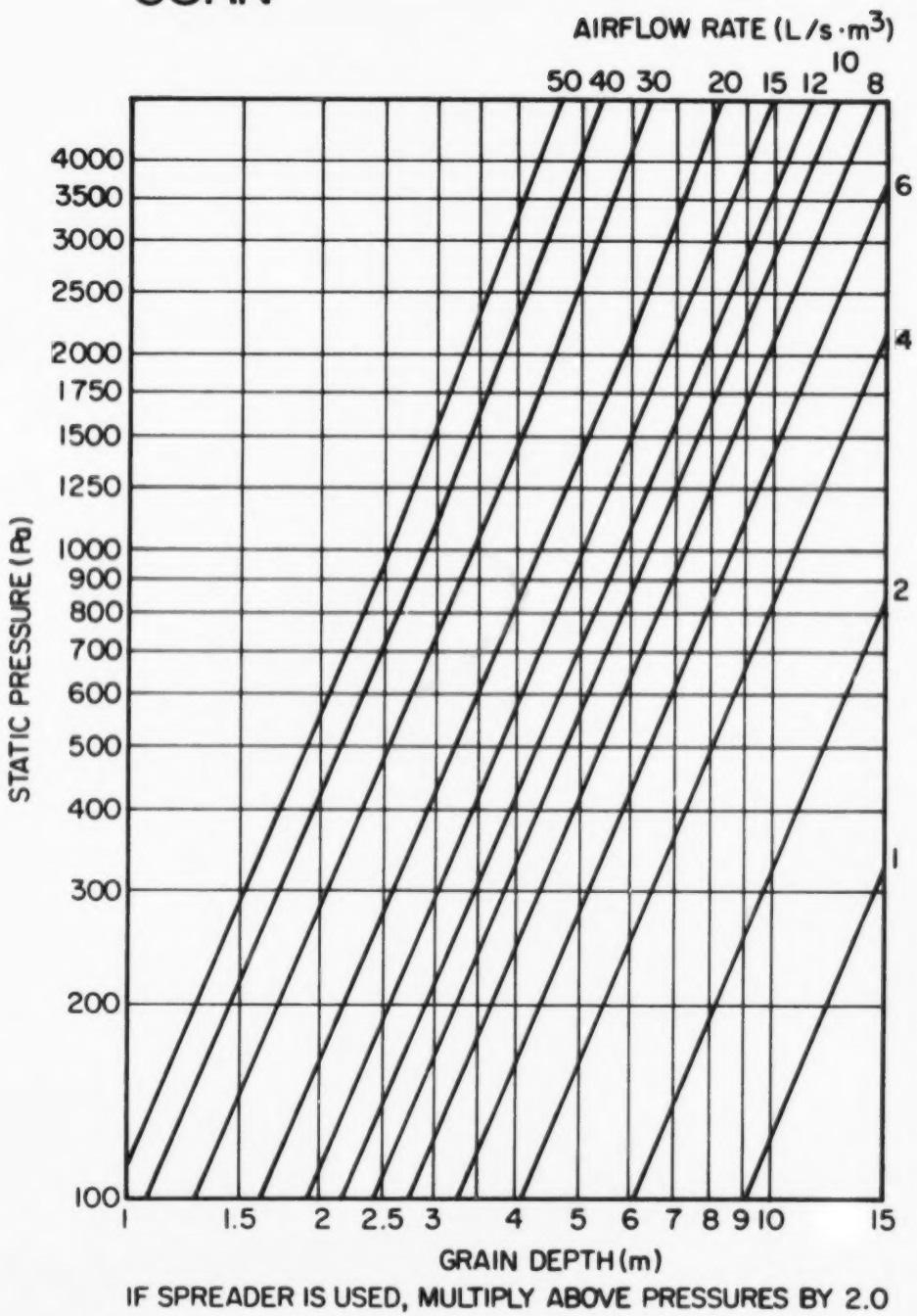


Figure 19 Airflow Resistance for Corn on a Fully Perforated Floor

Note: If only a portion of the floor is perforated, multiply the above pressures by an appropriate factor from the table below.

% of floor area that is perforated	Multiply pressure by
40	1.1
25	1.3
15	1.5

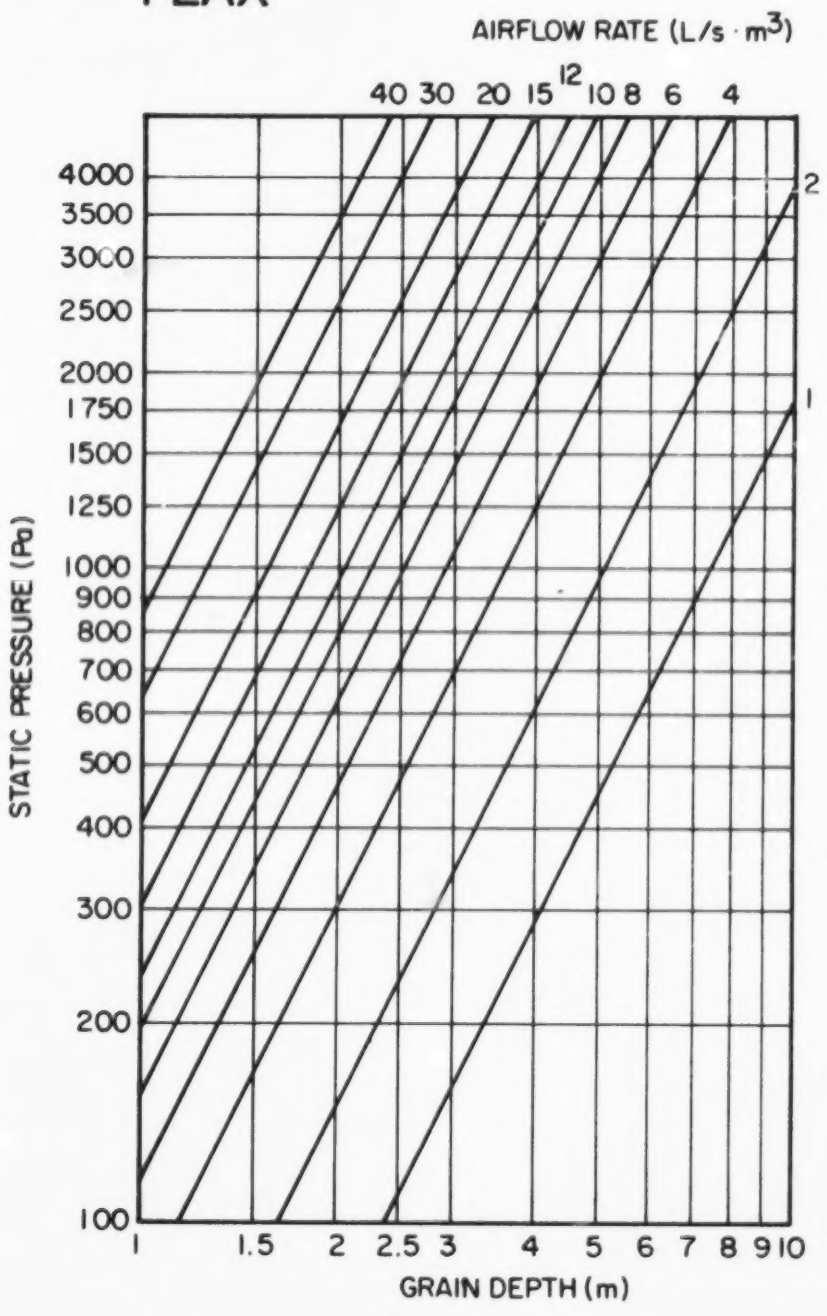


Figure 20 Airflow Resistance for Flax on a Fully Perforated Floor

Note: If only a portion of the floor is perforated, multiply the above pressures by an appropriate factor from the table below.

% of floor area that is perforated	Multiply pressure by
40	1.1
25	1.3
15	1.5

TABLE 6

Average Fan Outputs

Type: Axial Flow

HP	3/4	1	1.5 - 2	3 - 4	5 - 7	7 - 9	9 - 10.5
Diameter	12"	14"	18"	18"	24"	24"	24"
L/s Air Flow at Indicated Static Pressure							
125 Pa	880	1230	2180	2740	5040	5060	6270
250	420	910	1900	2550	4600	4760	5920
375	260	640	1570	2260	4380	4380	5500
500	140	470	1230	1900	4020	3990	5050
625		320	900	1480	3600	3570	4440
750		140	620	1140	3140	3140	3730
875		70	390	900	2610	2690	3000
1000			210	710	2140	2250	2400
1125			50	520	1730	1830	1890
1250				350	1350	1440	1500
1375				220	1010	1100	1110
1500				90	680	800	730
1625					510	580	290
1750					220	370	

Note: Actual fan performance for specific fans may vary considerably from the averages given in this table. Actual data from "Fan Test Results" or Prairie Agricultural Machinery Institute test reports should be used whenever possible.

TABLE 6 (continued)

Average Fan Outputs

Type: In-Line Centrifugal

HP	1.5	3	3	5
Diameter	18"	18"	24"	24"
	L/s Air Flow at Indicated Static Pressure			
250 Pa	1190	1510	1960	2220
500	1080	1420	1860	2100
750	980	1260	1790	1960
1000	860	1120	1660	1840
1250	510	760	1520	1700
1500		180	1420	1530
1750			1210	1210
2000			220	560

TABLE 6 (continued)

Average Fan Outputs

TYPE: Centrifugal 1750 rev/min				L/s Air Flow at Indicated Static Pressure	
HP / Pa	3	5	7.5	10	15
250 Pa	2320	3750	4430	6280	7200
500	2090	3360	4160	5970	6850
750	1830	3020	3850	5540	6450
1000	1460	2690	3490	5100	5950
1250	640	2260	3110	4660	5380
1500		420	2610	4110	4770
1750				3440	4000
2000				2960	3450

TABLE 6 (continued)

Average Fan Outputs

TYPE: Centrifugal 3450 rev/min			L/s Air Flow at Indicated Static Pressure		
HP / Pa	3	5	7.5	10	15
250 Pa	1500	1870	2520	3180	4820
500	1410	1770	2410	3040	4530
750	1320	1690	2300	2910	4320
1000	1210	1590	2190	2760	4130
1250	1100	1500	2060	2620	3930
1500	950	1390	1920	2480	3670
1750	720	1280	1780	2330	3450
2000	550	1110	1630	2170	3160
2250	320	860	1480	1980	2870
2500	90	330	1310	1750	2610
2750		100	1000	1410	2240
3000			700	1000	1700
3250			490	790	1380
3500			220	500	700

TABLE 7

Air Movement System Guidelines

Air Flow (L/s)	Minimum Cross Sectional Duct Area (m^2)	Minimum Perforated Floor Area (m^2)		Minimum Roof Vent Area (m^2)
		Cereal Floor	Canola (Rapeseed) Floor*	
250	0.03	1.1	3.3	0.05
500	0.07	2.2	6.7	0.10
750	0.10	3.3	10.0	0.15
1000	0.13	4.4	13.3	0.20
1250	0.17	5.6	16.7	0.25
1500	0.20	6.7	20.0	0.30
1750	0.23	7.8	23.3	0.35
2000	0.27	8.9	26.7	0.40
2250	0.30	10.0	30.0	0.45
2500	0.33	11.1	33.3	0.50
3000	0.40	13.3	40.0	0.60
3500	0.47	15.6	46.7	0.70
4000	0.53	17.8	53.3	0.80
4500	0.60	20.0	60.0	0.90
5000	0.67	22.2	66.7	1.00
5500	0.73	24.4	73.7	1.10
6000	0.80	26.7	80.0	1.20
6500	0.87	28.9	86.7	1.30
7000	0.93	31.1	93.3	1.40
7500	1.00	33.3	100.0	1.50
8000	1.07	35.6	106.7	1.60
8500	1.13	37.8	113.3	1.70
9000	1.20	40.0	120.0	1.80
9500	1.27	42.2	126.7	1.90
10000	1.33	44.4	133.3	2.00

*For the minimum canola (rapeseed) floor areas listed, add 50 Pa to the system airflow resistance; if the area is ½ of that listed, add 150 Pa; and if the area is ⅓ of that listed add 350 Pa.

TABLE 8

Sizing Guidelines for Round Perforated Tubes

Tube Diameter	Maximum Airflow	Minimum Perforated Tube Length*	
		Cereal Perforations	Canola (Rapeseed) Perforations
300 mm (12")	550 L/s	3.2 m	9.6 m
350 mm (14")	750 L/s	3.7 m	11.2 m
450 mm (18")	1250 L/s	4.8 m	14.5 m
600 mm (24")	2200 L/s	6.4 m	19.2 m

*Based on maximum recommended airflow. For lower airflows, tube length may be reduced proportionately.

AIRFLOW WORKSHEET

NAME: _____ ADDRESS: _____

BIN MAKE AND MODEL: _____ GRAIN: _____

DESIRED AIRFLOW RATE: _____ (L/s)/m^3 — (1) (Tables 3 or 4)

A) Bin Dimensions and Volumes (Table 5)

Height to Eaves: _____ m — (2)

Grain Volume: _____ m^3 — (3)

B) Fan Selection Parameters

i) Airflow Required = Airflow Rate (1) × Grain Volume (3)

= _____ (L/s)/m^3 × _____ m^3

Air Flow = _____ L/s

ii) Static Pressure

Use Airflow Resistance Graph (Figures 15, 16, 17, 18, 19, or 20)

Follow the line for the desired Airflow Rate to where it crosses the desired Grain Depth. Then go across to the left of the chart and read the static pressure.

Static Pressure = _____ Pa

Multiply by partial floor factor if applicable _____ × _____ Pa = _____ Pa.

Add extra pressure drop for canola (rapeseed) floor if applicable (see note Table 7) _____ Pa.

Static Pressure required _____ Pa.

C) Fan Required

From the fan tables choose the fan which will deliver the Airflow at the Static Pressure required.

Fan: Type _____

HP _____

Size _____

D) System Guidelines

Determine the following for the selected Airflow.

Minimum Duct Area = _____ m^2 (Table 7)

Minimum Perforated Floor area – greater of _____ m^2 (Table 7)

OR % of Floor Area = _____ % (Table 4) × _____ m^2 (Table 5)

= _____ m^2

Minimum Roof Vent Area = _____ m^2 (Table 7)